FINAL REPORT

on

EVALUATION OF A WIND TURBINE ELECTRIC POWER GENERATOR

for

National Aeronautics and Space Administration
Marshall Space Flight Center

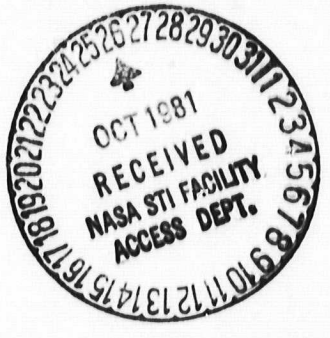
on

NASA NAG-8007 Research Grant

for

Grant Period

June 1, 1980 to September 15, 1981



by

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October 15, 1981

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NASA NAG-8007

William B. Swim, Project Director
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INTRODUCTION

The results of experimental work under NASA NAG-8007 and Supplement 1 to that Research Grant are reported herein. The work, wind tunnel evaluation of NASA's Wind Wheel Turbine (WWT) was initiated in June 1980 and completed in August 1981. The technical monitor on the project was, the WWT inventor, Mr. John W. Kaufman, Fluid Dynamics Branch, Atmospheric Sciences Division.

Objectives

The three objectives of the project were to:

1. Provide a technical assessment of the aerodynamic performance of the WWT.

2. Evaluate the potential of the wind wheel turbine in utilizing wind as an alternate power source and

3. Develop scaling parameters to predict the aerodynamic performance of WWT prototype sized to produce 3, 9, 30 and 100 kw outputs in a 6.7 m/sec (15 miles per hour) wind.

Scope

The following tasks were completed under this Grant:

A. Construct a scale model, Model A, of the WWT from description supplied by NASA.

B. Design and set up a performance measuring system for the WWT in the Tennessee Technological University (TTU) wind tunnel.

C. Measure the performance, rotor speed and torque, of Model A WWT at steady wind tunnel speeds of 28, 33 and 38 meters/sec (62.5, 73.8 and 85.2 mph).

D. Design, set up and run a spin-up, spin-down test system for the WWT, Model A.

E. Instrument and measure the performance of Model K WWT, supplied by NASA, at steady wind tunnel speeds of 28, 33 and 38 meters/sec.

F. Measure the performance of the individual wind inlets, singularly and in pairs, for the Model K WWT.

G. Analyze the performance data and compare to data on other types of wind turbines.

H. Extrapolate the performance of the models to homologous prototype with shaft outputs of 3, 9, 30 and 100 kw.

EXPERIMENTAL SYSTEMS

Wind Tunnel Tests

Steady state performance of the WWT models were run in the Tennessee Technological University Wind Tunnel, a low velocity recirculation tunnel with a test section 2 ft high x 3 ft wide x 10 ft long. The turbine models were mounted on the center line of the test section and connected to an external torquemeter and revolution counter by a shaft extending through the side of the test section. Torque measurements were made with a Lebow strain gage type torquemeter and digital indicator/amplifier. The torque sensor contained a 60 tooth gear and magnetic pickup. The gear and pickup system provided a pulse signal to an electronic counter/timer which would display the rotor speed. Wind tunnel velocity was measured by a pitot tube connected to a micromanometer. The wind tunnel test system is illustrated in Figure 1.

Spin Up - Spin Down Test System

Transient data on WWT, Model A, was obtained using an open, blow through wind tunnel illustrated in Figure 2. The model was mounted at the exit of the tunnel. Wind velocity was determined by an upstream pitot probe and inclined manometer which was calibrated against a velocity probe located at the position

where the model would be placed. The rotor speed of the model was measured by a magnetic pickup and 60 tooth gear, set out of the wind stream and connected to the rotor by a light aluminum shaft. Timed count rates during spin up and spin down provided data on rotor acceleration.

Spin-up tests were run by placing the WWT model, with rotor locked, in the air stream with the desired wind speed. The rotor was released and the revolutions as a function of time were recorded. When the steady state speed was reached, this maximum shaft speed was also recorded.

Spin-down tests were run starting from the steady state conditions of the spin-up tests. A damper in the wind tunnel was closed to divert the flow out the side of the tunnel. Speed-time data was recorded as the rotor coasted to a stop. These tests were run at model inlet air velocities of 10.4, 11.7, 13.2 and 16.5 meters/sec (2050, 2300, 2600 and 3250 ft/min).

Model A, WWT

A scale model WWT, designated the Model A, was built of plexiglass following the descriptive sketches supplied by NASA. The dimensions of the Model A, with a rotor diameter of 14 cm (5.51 in.), are given in Figure 3, 4 and 5. A photograph of the completed unit is shown in Figure 6.

The Model A WWT had wheel dimensions and measured wind collector areas as shown below:

Wheel: dxw & projected area	5 1/2" x 1 7/8"	10.31 sq in	or	66.5	sq cm
Front collector	3 1/4" x 2 13/16"	9.14 sq in	or	59.0	sq cm
Top projection of rotor	1 7/8" x 2 3/4"	5.16 sq in		33.3	sq cm
Side collectors	∿ 2 13/16" x 3" ea	16.74 sq in		108.0	sq cm
Bottom deflector	2 3/4" x 3/4"	2.06 sq in		13.3	sq cm
Total Collector Area		33.13 sq in		213.7	sq cm

Model K, WWT

The Model K WWT, an aluminum model built and supplied by NASA, was about 40% larger than the Model A. It is illustrated by sketches in Figure 7, 8 and 9 and by

photograph in Figure 10. The major dimensions are shown in the sketches as scaling units.

The measured wheel dimensions and wind collector areas for the Model K WWT are:

Wheel: dxw & projected area	8 3/16" x 2 3/4"	= 22.52 sq in	or 145.26 cm^2
Front collector	∿ 3 17/18" x 3 1/2"	13.85 sq in^2	89.35 cm^2
Top projection of rotor	2 3/4" x 4 9/16"	12.55 sq in^2	80.97 cm^2
Side collectors	∿ 4 1/8" x 3 15/16"	31.96 sq in	206.19 cm^2
Bottom deflector	3 13/16" x 1 1/4"	4.76 sq in	30.71 cm^2
Total Collector Area		63.12 sq in	407.22 cm^2

RESULTS

Performance Tests

Power and torque test data, runs A-1 to A-11 for the Model A WWT and K-1 to K-7 for the Model K WWT are attached in the Appendix A. The methods of data reduction, to obtain torque shaft power and wind energy, are shown in Apperdix B.

Representative performance curves for Model A, torque and power plotted against shaft speed for wind velocities of 28, 33 and 36 m/sec (5500, 6500 and 7000 ft/min) are plotted as Figures 11, 12 and 13.

Performance curves for the Model K WWT, at wind velocities of 20 to 36 m/sec (4700 to 7000 ft/min) are given in Figures 14, 15 and 16.

Nondimensional performance measures, torque coefficient C_T, and power coefficient C_P, are plotted vs the velocity ratio in Figure 17.

Spin Up and Spin Down Tests

Data for the spin-up and spin-down tests, run using the Model A WWT, are given in Appendix C. The results of the spin tests are plotted in Figures 18 and 19. Also shown on these plots are the earlier Kaufman spin test data[1], taken using an earlier stainless steel WWT model.

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[1]Advanced and Innovative Wind Wheel Turbine, M.S. Thesis of John W. Kaufman, University of Tennessee, December 1979.

Discussion

The performance data from Models A and K are similar. Figures 11, 12 and 13 for the Model A and Figures 14, 15 and 16 for the Model K show that both have almost a linear decreasing shaft torque with increasing shaft speed. The maximum rotor speed, at zero shaft torque, occurs when bearing friction and rotor windage losses balance the wind energy extracted by the rotor.

An instability in the Model A torque curve, a local flatening of the torque with speed, generally occurs at least once in each performance curve. The flat spots in the torque curve can cause a relative peak in power output. This instability or hysteres s does not appear to be an experimental fluke. All the tests of the Model A exhibited this instability phenomena at about 65% of max speed. A second instability occurs at about 20% of max rotor speed. A third instability occurs when the rotor is locked. The locked-rotor torque is strongly dependent on the position of the rotor blades with respect to the housing flow paths. A 2 to 1 swing in stall torque occurred as the position of the locked rotor varied over a 45° interval, a blade passage interval.

The Model K performance curves were smoother than the Model A and did not exhibit the same type of flat spots. However the K model had the same variation of stall torque, with the torque varying strongly with the static blade position.

The normalized performance curves, Figure 17, compare the Models A and K for the several tests. The better performance of the larger Model K was expected based on size considerations. But the magnitude of improvement was larger than anticipated. Using a Reynolds Number analogy to deduce the influence of size on turbine performance,

$$\frac{1 - \eta_1}{1 - \eta_2} = \left(\frac{D_2}{D_1} \right)^{0.2}$$

would indicate the losses in the smaller turbine would exceed the larger units loss by 7%. Measured decreases in C_p, the power coefficient between the Model K and the Model A were found to be around 42%.

The significance of the spin data is rather obscure. The validity of comparing the current Model A data to earlier NASA data appears nil. The spin data is a measure of the inertia of the rotor, the frictional losses in the turbine rotor and lastly the efficiency of the turbine in converting wind energy into mechanical energy. The performance assessment of the WWT can best be done by eliminating the confusing influences of inertia and rotor frictional losses. This was done in the steady state performance measurements discussed above. The direct measure of performance is much superior to the indirect spin test methods.

Performance of Individual Wind Collection System

The Model K WWT was run with only one or two of the three air collection systems being open to the wind. One or more inlets--front, side ports or top--were covered to prevent wind from entering the wheel via that passage. The measured performance of the turbine was normalized by dividing by a wind energy factor scaled to the collector area actually open to the wind. This procedure allows the effectiveness of each collector & duct system to be evaluated individually. Comparing the decrease in normalized performance of two systems operating together from the performance of the individual systems gives a measure of the interference of one system with another.

It is clear that the top port is the most efficient air collection system, based on peak power coefficient. The front port is next and the side wings have the lowest peak power coefficient, all based on the actual wind collection area open.

Combining the operating of the front and wheel top collectors reduces the power coefficient to the lower of the two. The two collectors together are little better than the front port alone. The performance of the complete wind turbine, the heavy solid line on the C_P & C_T plots, show that the performance comes up slightly when adding the side collectors to the front and the wheel wind inlets. But the performance of the other two collector configurations, wheel top and sides or

front and sides, is reduced by adding the third collector. Combinations including the front and the wheel top have reduced performance. The air flows from the front and the wheel top are shown to have strong negative interactive effects.

These results show that strong interactions--the flow from one collector bucking or flowing counter to a second stream--can cause a sharp degregation of performance. The collectors and wheel are not designed to work harmoniously together.

One of the primary WWT design problems is the paddle wheel, an inefficient low speed design. The flow entering a bucket to generate a rotor torque must turn around at the bottom of the blade passage and flow out counter to the in-flow stream. This is an inefficient design. The flow leaving a blade passage may, due to wheel rotation, find itself flowing counter to a fresh air stream from another collector system. This second counter current stream again takes its toll, reducing turbine output and lowering the efficiency.

The paddle wheel blade design, inherently counter flow in operation, needs to be replaced with a pure radial in-flow rotor. The wind would be introduced to aerodynamically shaped blades on the periphery of the rotor. The air passes through the blade passages, producing a rotor torque. The air would continue its radial inflow and be discharged through one or two axial openings at the center of the rotor.

Scaling

The performance of the WWT models can be scaled-up using turbomachinery similarity rules or "fan laws" and a model of the behavior of flow losses with unit size. The similarity rules for incompressible flow are

$$\text{Flow:} \quad Q \propto ND^3$$

$$\text{Head:} \quad H \propto N^2D^2$$

$$\text{Power:} \quad P \propto N^3D^5$$

A well accepted turbine loss model, the Moody model, is given on page 5. This

flow model can be used to determine the viscous flow losses and performance of WWT prototypes from the measured wind tunnel performance of the WWT models. The Moody loss model is:

$$\frac{1 - \eta_1}{1 - \eta_2} = \frac{(\text{flow losses})_1}{(\text{flow losses})_2} = \left(\frac{D_2}{D_1} \right)^{0.2}$$

This model can also be based on Reynolds number, $N_{Re} = \frac{DV}{\nu}$ rather than just size. For model tests in air, the speed ratio between model and prototype and the diameter ratio influence the flow losses such that

$$\frac{(1 - \eta_1)}{(1 - \eta_2)} = \frac{(\text{flow losses})_1}{(\text{flow losses})_2} = \left(\frac{N_{Re_2}}{N_{Re_1}} \right)^{0.2}$$

Adapting these relationships to the wind turbine scaling problem yields:

$$\text{Wind power} = P_w \propto V_w^3 D^2$$

$$\text{Power coefficient} = C_p = \frac{P_{shaft}}{P_{wind}}$$

$$\text{Shaft power} = P_{sh} \propto C_p V_w^3 D^2$$

The Model K data needed in scaling is:

$$C_{P_{Peak_M}} = 0.019$$

$$\text{at } V_{w_M} = 33 \text{ m/sec and}$$

$$D_{w_M} = 0.208 \text{ m with}$$

$$\text{Acollector}_M = 0.0145 \text{ m}^2$$

The prototype wind speed selected, 15 mph, is

$$V_w = 6.7 \text{ m/sec}$$

The relationships for prototype shaft power, based on size only, is:

$$P_{sh}|_p = 36.3 \quad D_p^2 - 25.7 \quad D_p^{1.8} \qquad \text{watts}$$

The relationship for prototype shaft power can be modified to include Reynolds number influences by replacing D_2/D_1 with N_{Re_2}/N_{Re_1}. The expanded expression

for prototype flow losses, with $\nu_M = \nu_p$, is

$$\left(\frac{0.6 - C_{p_M}}{0.6 - C_{p_p}}\right) = \left(\frac{D_p V_p}{D_M V_M}\right)^{0.2}$$

The shaft power prediction equation, which includes size and velocity influences, is:

$$P_{sh}|_p = 36.3 \quad D_p^{\,2} - 35.3 \quad D_p^{\,1.8}$$

Prototype wheel diameters, for 4 power levels, were calculated using the above two models and a prototype wind velocity of 6.7 m/sec. The results, for a prototype operating at the optimum speed ratio of 0.42, are tabulated below.

Turbine Shaft Power kW	Turbine Rotor Diameter meters	
	Loss $\sim D^{0.2}$	Loss $\sim (DV)^{0.2}$
3	12	14
9	20	23
30	36	39
100	63	69

Conclusions and Recommendations

The normalized performance of the K Model WWT is plotted on Figure 21 with the ideal propeller windmill performance and the measured performance curves for other current windmill designs. The WWT performance is almost lost in the lower left hand corner of the plot. The WWT does not have much velocity ratio range, only up to ~ 1, and has very disappointing performance, $C_p \sim 0.02$, as compared to 0.4 for the high speed propeller designs.

Selecting the best single wind collection system from Figure 20, the wheel top of the Model K, and adding this to the comparative performance map, Figure 21, offers little encouragement. The wheel-top-only peak C_p was only 0.04 to 0.044. And the effectiveness of the one collector system design is poor for a large structure was required to support a small collector area.

The advantages of mechanical strength and safety are inherent to the WWT housed rotor design. These advantages might be preserved in a competitive design if a radial in-flow rotor were available. This new rotor could be fed from a large collector designed to provide a uniform, symmetric flow to the rotor inlet. The rotor exhaust would leave axially and be swept out with the passing wind. Such a system, carefully designed, could rival the high speed propeller type turbines in performance. The major problem would be keeping the wind turbine design small and light enough that its installed cost would still be competitive.

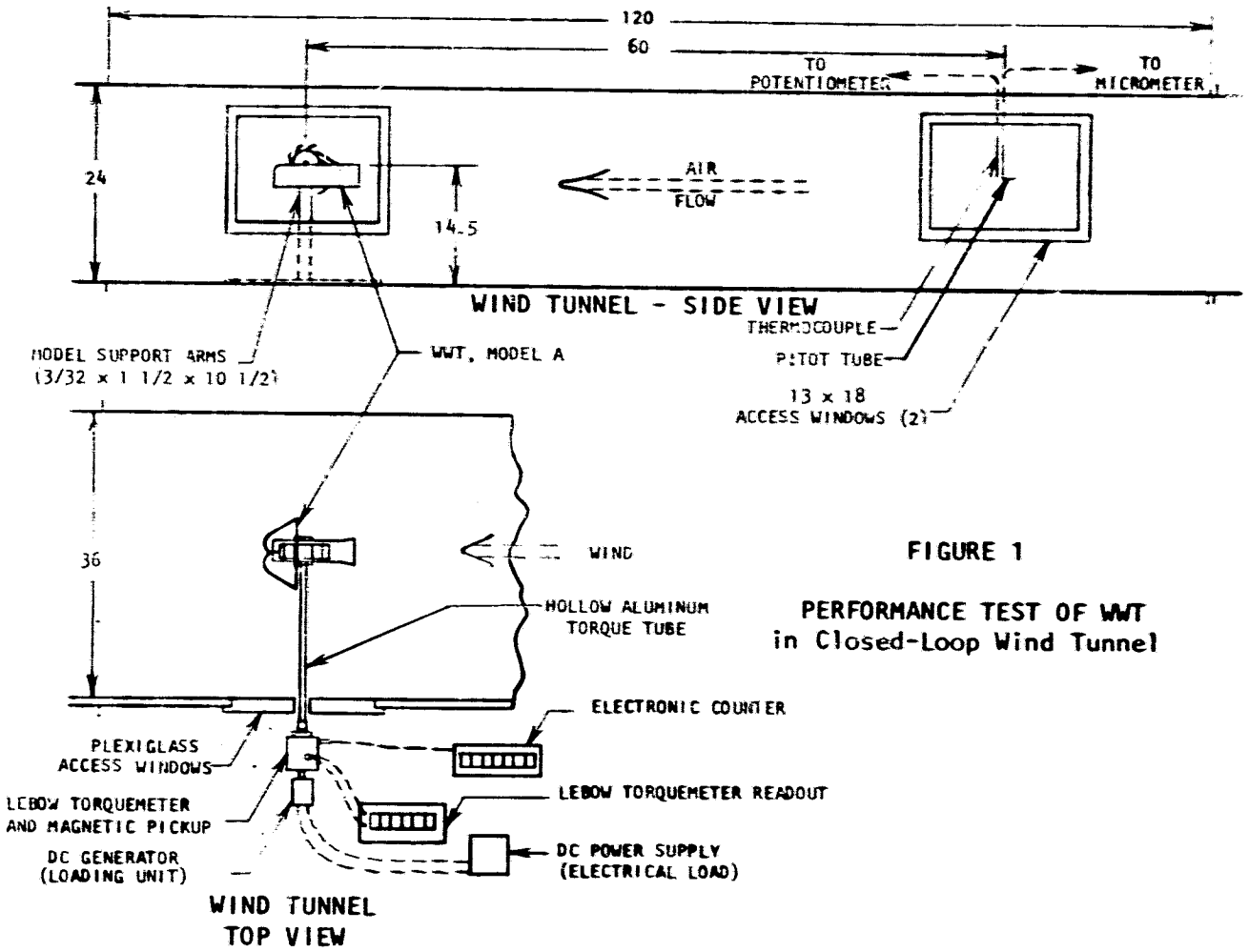
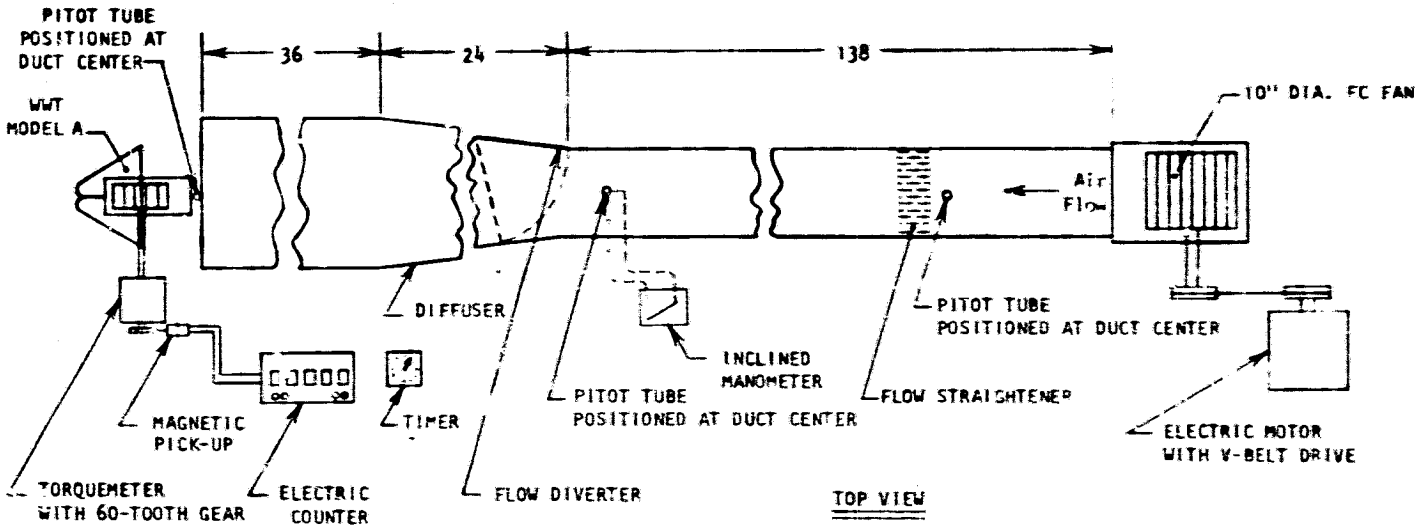
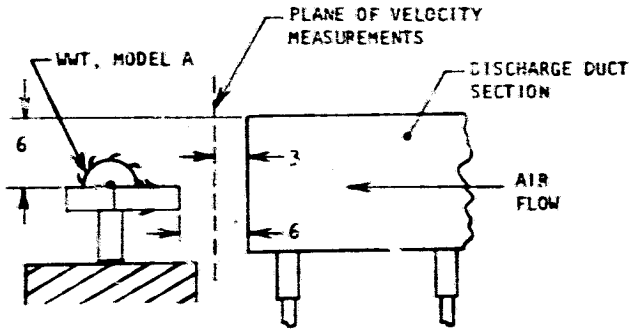


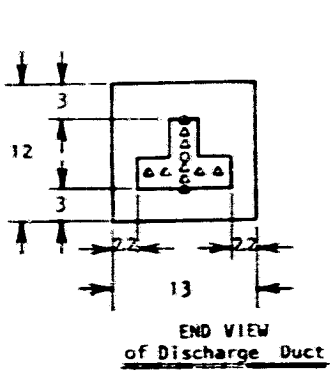
FIGURE 1

PERFORMANCE TEST OF WWT in Closed-Loop Wind Tunnel

ALL DIMENSIONS IN INCHES







○ PITOT TUBE

▲ ANEMOMETER TEST POINTS SPACED ON 1" CENTERS VERTICALLY AND 1½" CENTERS HORIZONTALLY

ALL DIMENSIONS IN INCHES

FIGURE 2

BLOW THROUGH WIND TUNNEL
Used for Spin-Up and Spin-Down Tests

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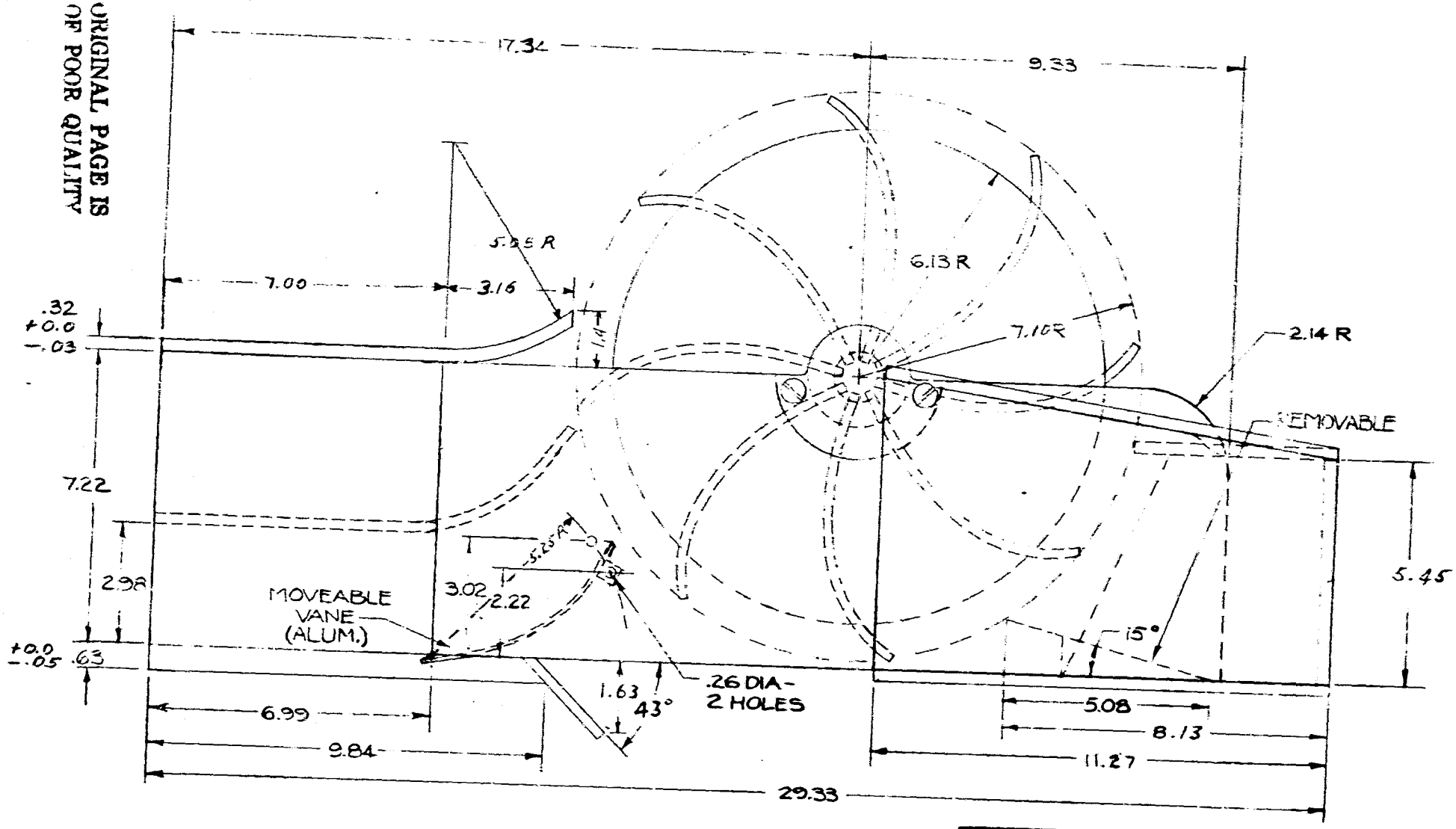
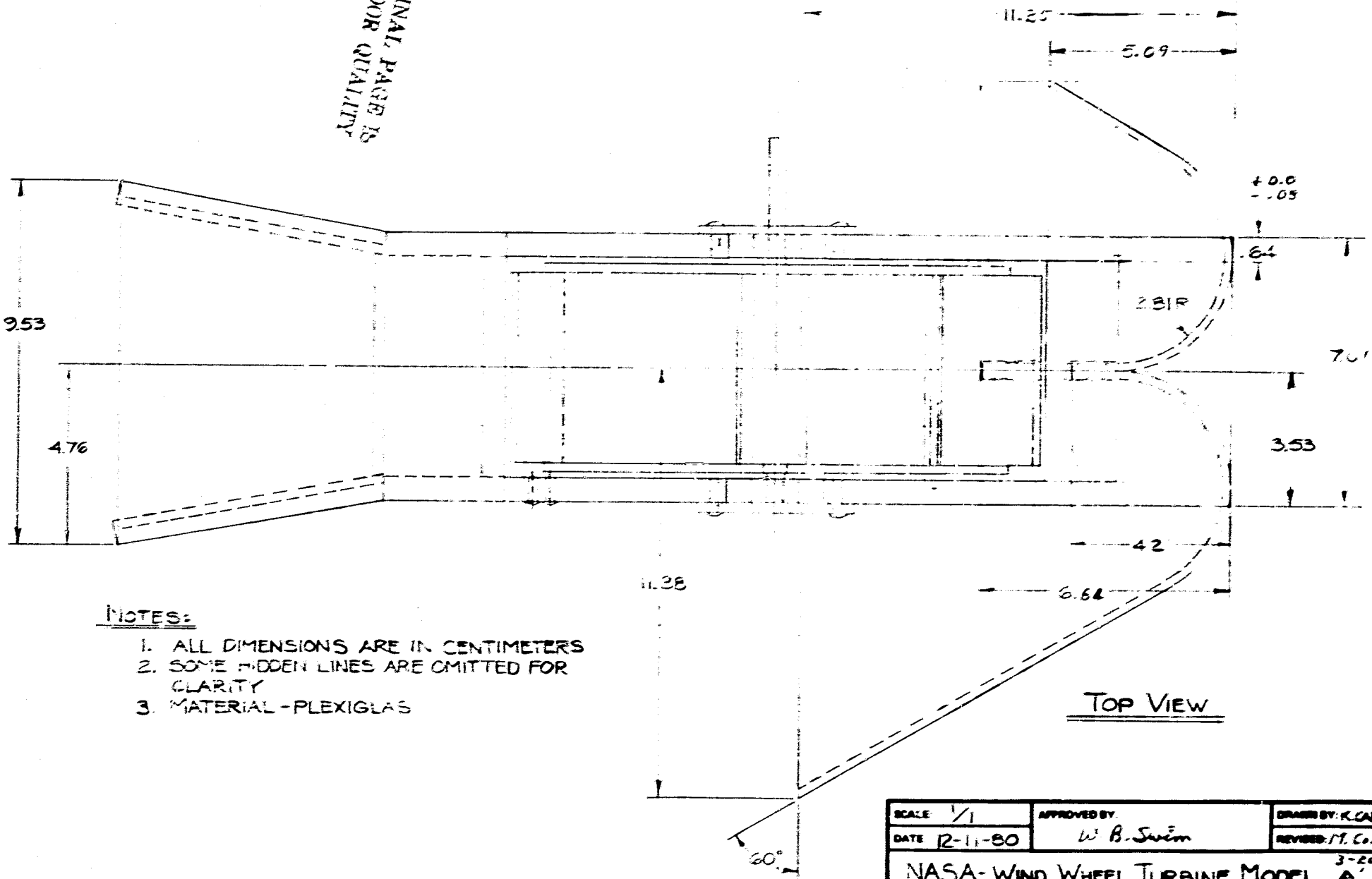


FOR NOTES SEE TOP VIEW

LEFT SIDE VIEW

FIGURE 3 MODEL A WWT SIDE VIEW

SCALE: 1/1	APPROVED BY: W.B. Swim	DRAWN BY: K. CARROLL
DATE: 12-11-80		REVISED: M. Collick 3-20-81
NASA- WIND WHEEL TURBINE MODEL A		
TENN. TECH UNIV. DEPT. OF MECH. ENGR.		DRAWING NUMBER WT-1



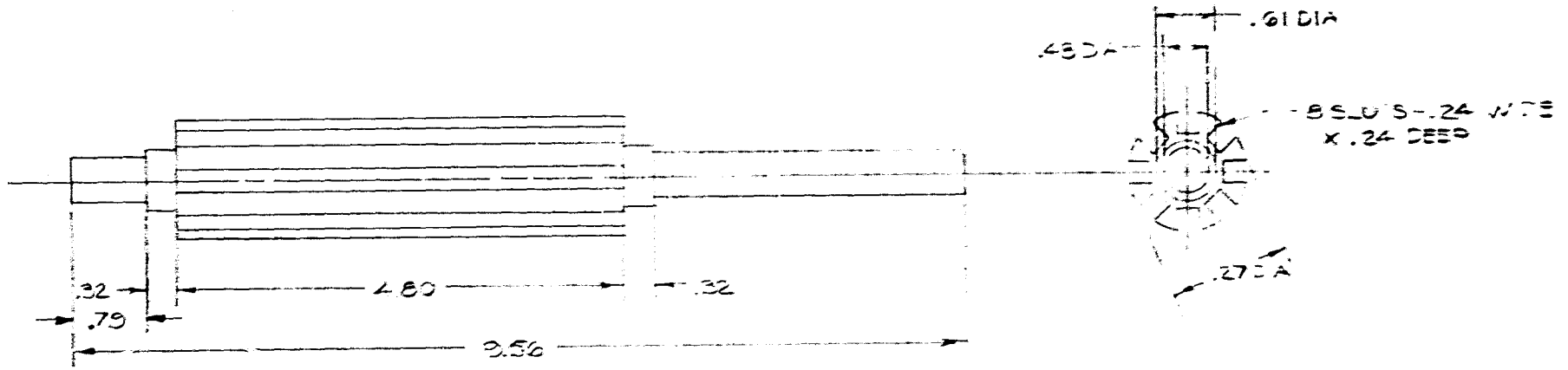
NOTES:

1. ALL DIMENSIONS ARE IN CENTIMETERS
2. SOME HIDDEN LINES ARE OMITTED FOR CLARITY
3. MATERIAL - PLEXIGLAS

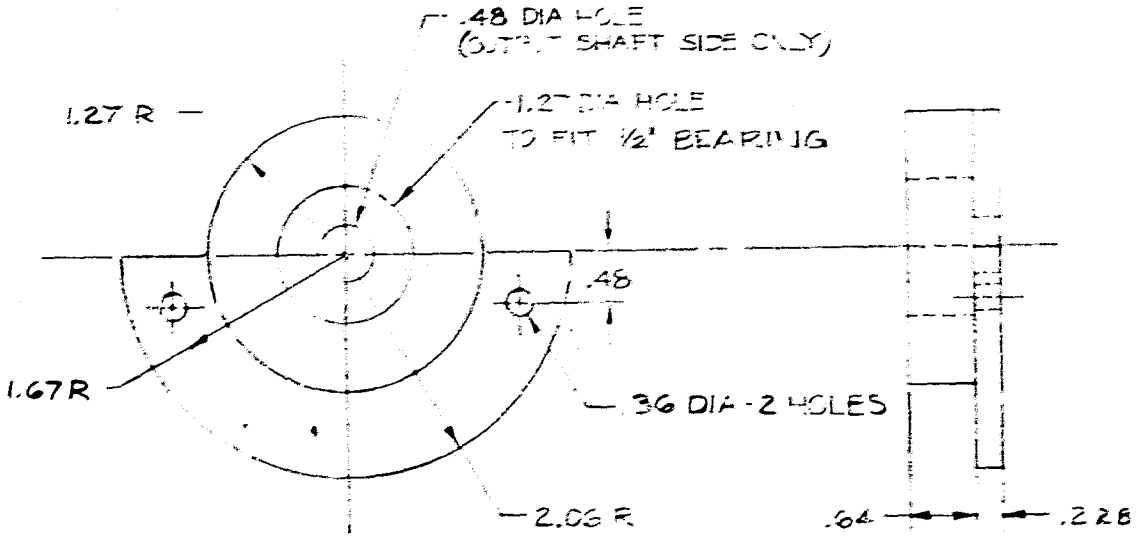
TOP VIEW

SCALE 1/1	APPROVED BY W. B. Swim	DRAWN BY: K. CARROLL
DATE 12-11-80		REVISED: M. Collier 3-26-81
NASA-WIND WHEEL TURBINE MODEL A'		
TENN. TECH. UNIV. DEPT. OF MECH. ENGR		DRAWING NUMBER WT-2

FIGURE 4 MODEL A WWT TOP VIEW



TURBINE SHAFT



BEARING HOLDER - 2 REQ'D

NOTES:
1. ALL DIMENSIONS ARE IN CENTIMETERS
2. MATERIALS:
SHAFT- ALUMINUM
HOLDER- PLEXIGLASS

SCALE 2/1	APPROVED BY W.B. Swim	DRAWN BY K. CARROLL
DATE 12-11-80		REVISED M. COLLICK 3-26-81
NASA-WIND WHEEL TURBINE. MODEL A		
TENN. TECH. UNIV. DEPT. OF MECH. ENGR.		DRAWING NUMBER WT-3

FIGURE 5 MODEL A WWT ROTOR DETAILS

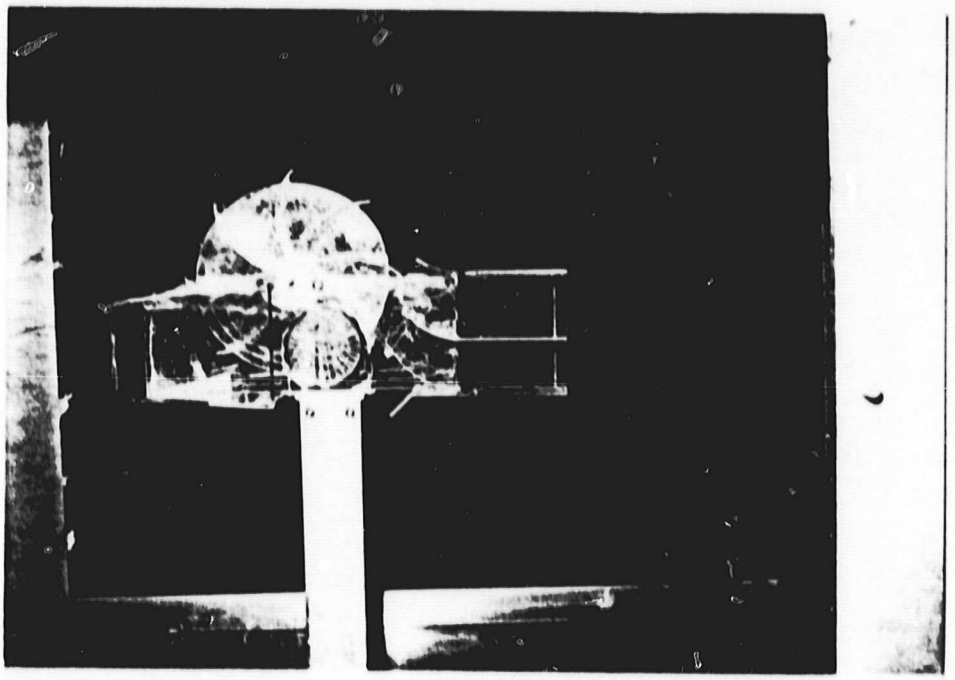


FIGURE 6

MODEL A WWT WIND TURBINE
Mounted in Wind Tunnel

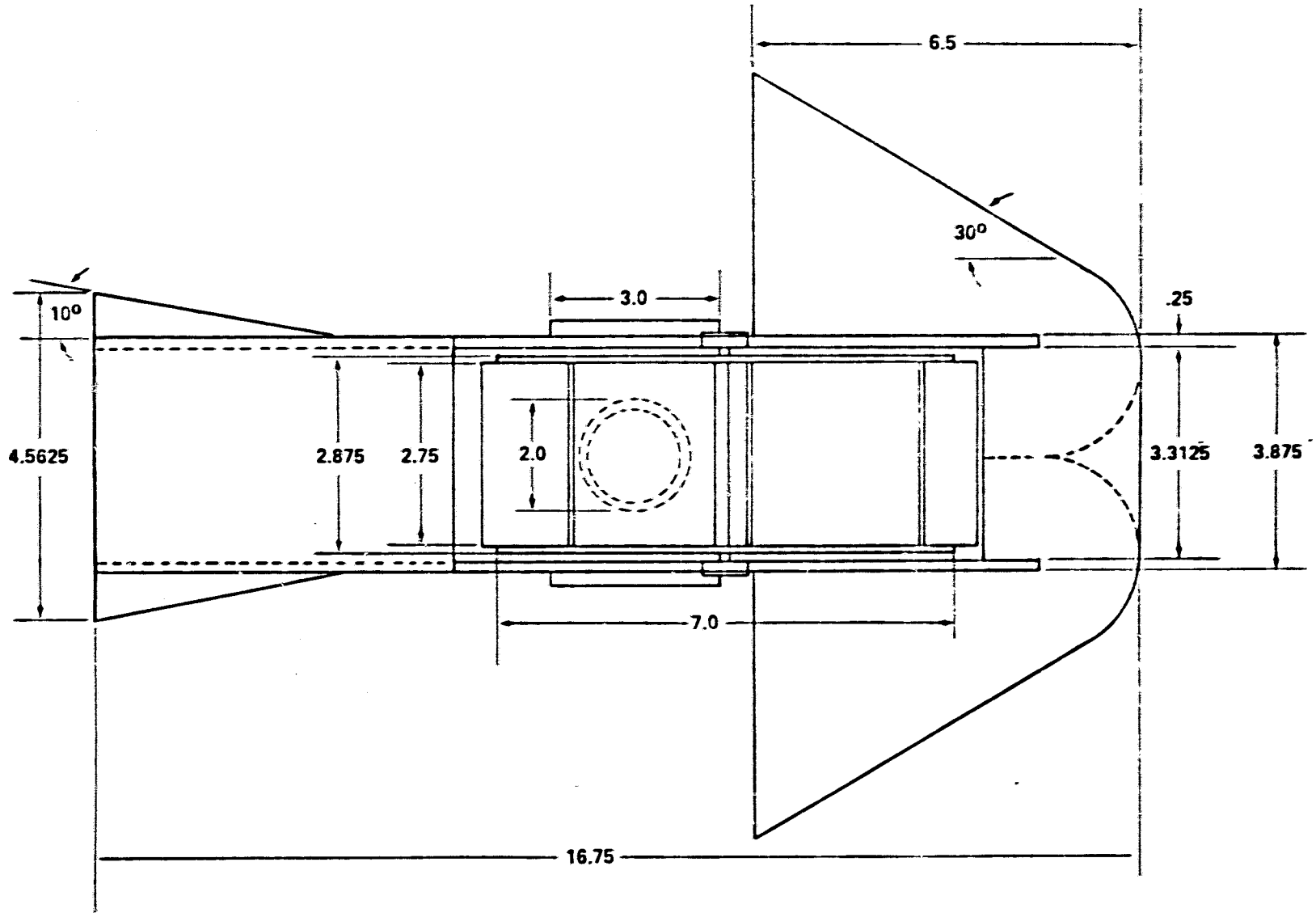


FIGURE 7 MODEL K WWT TOP VIEW

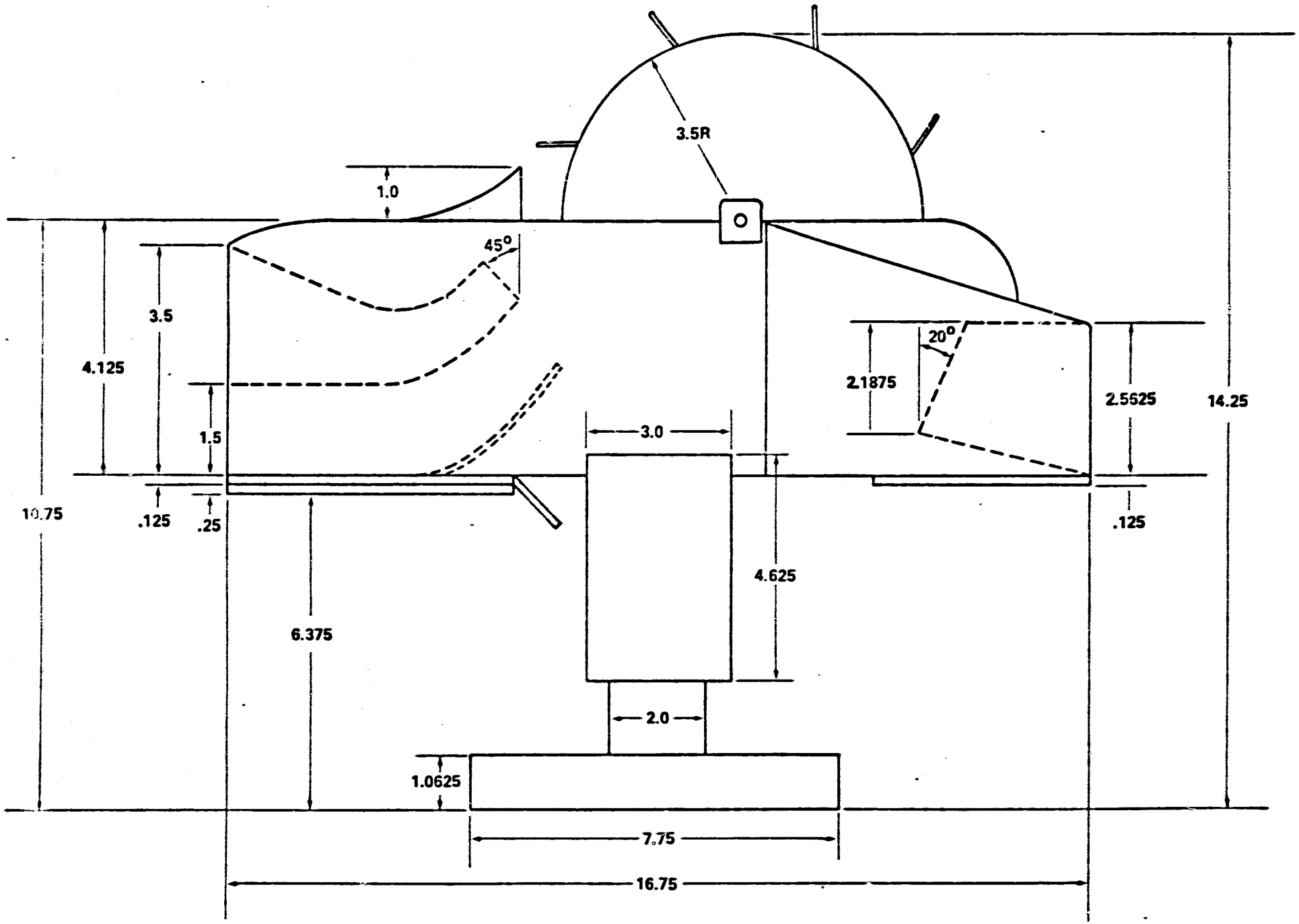


FIGURE 8 MODEL K WWT SIDE VIEW

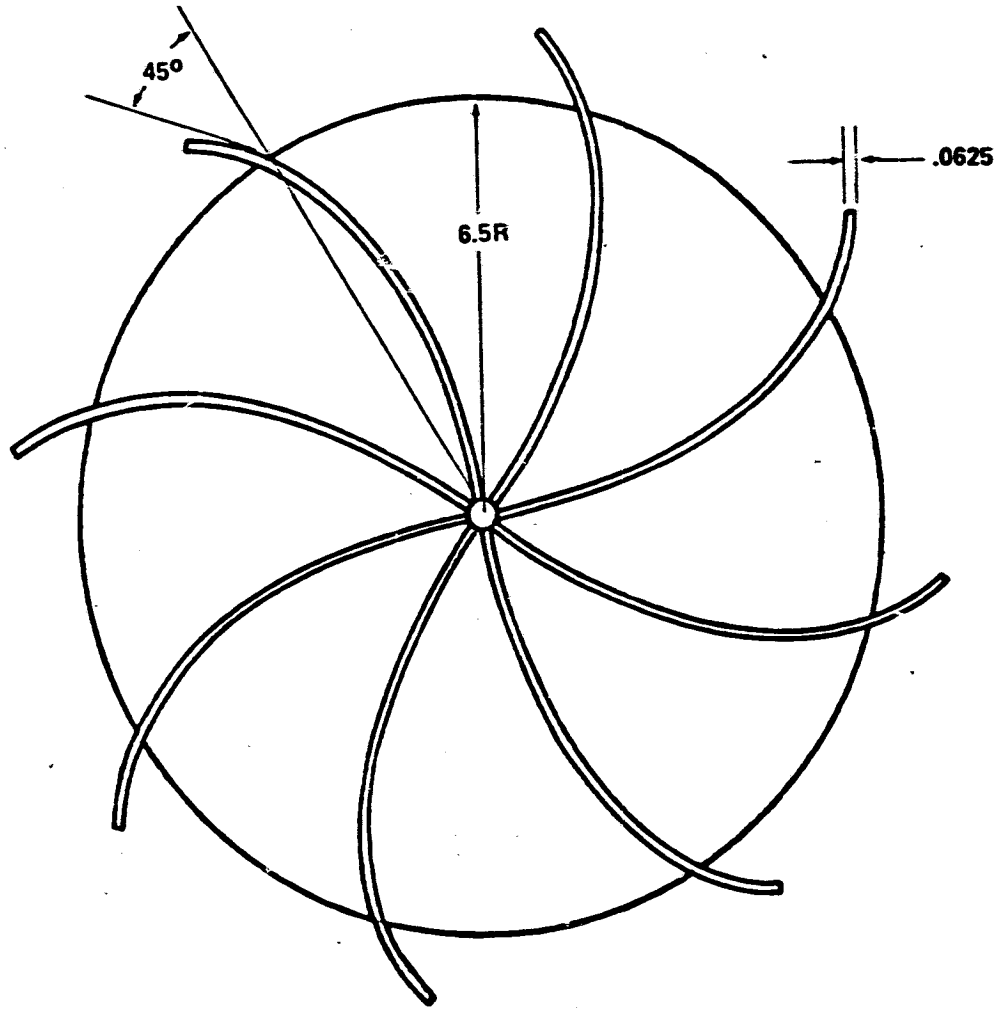


FIGURE 9 MODEL K WWT ROTOR

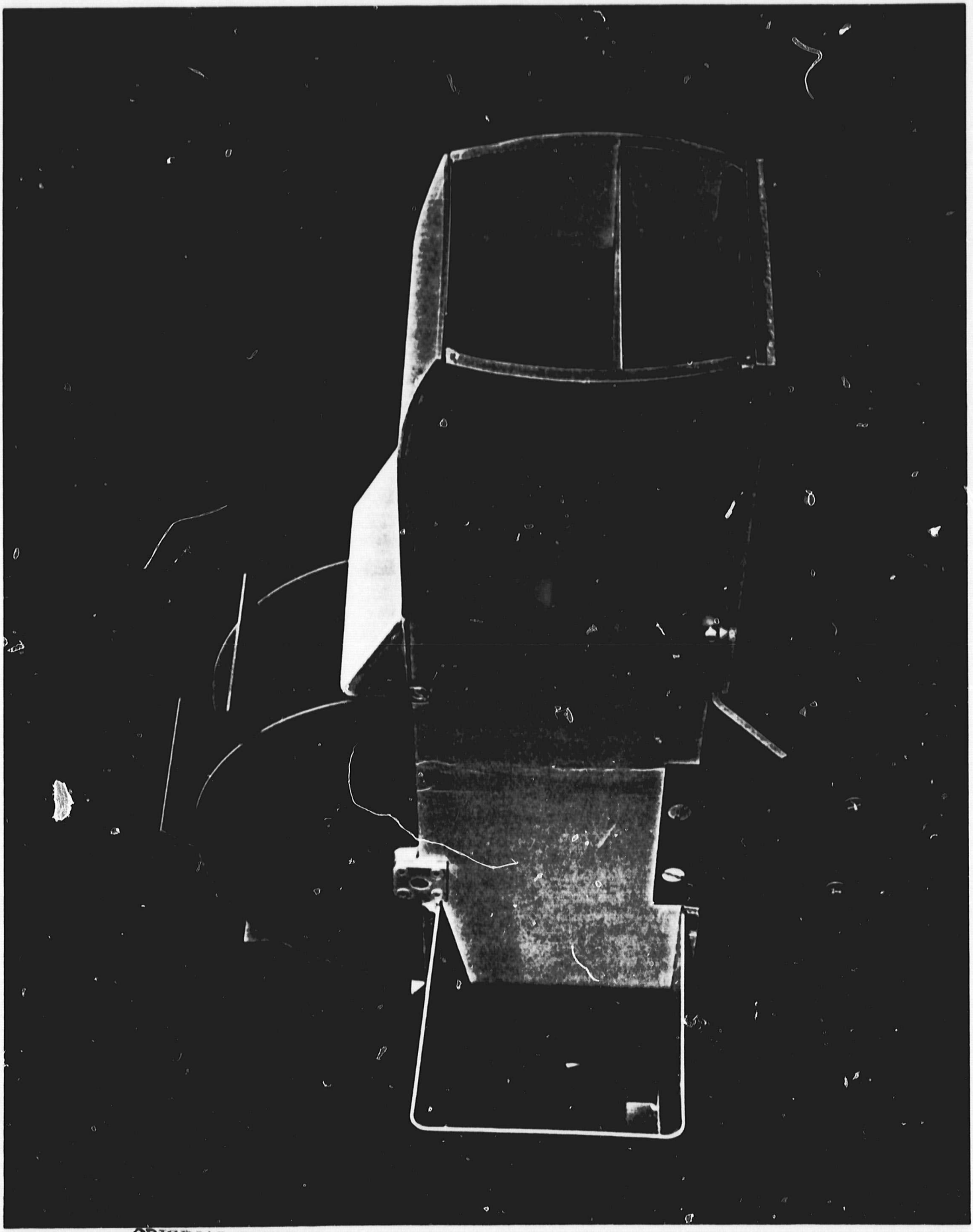


FIGURE 10 MODEL K WMT WIND TURBINE

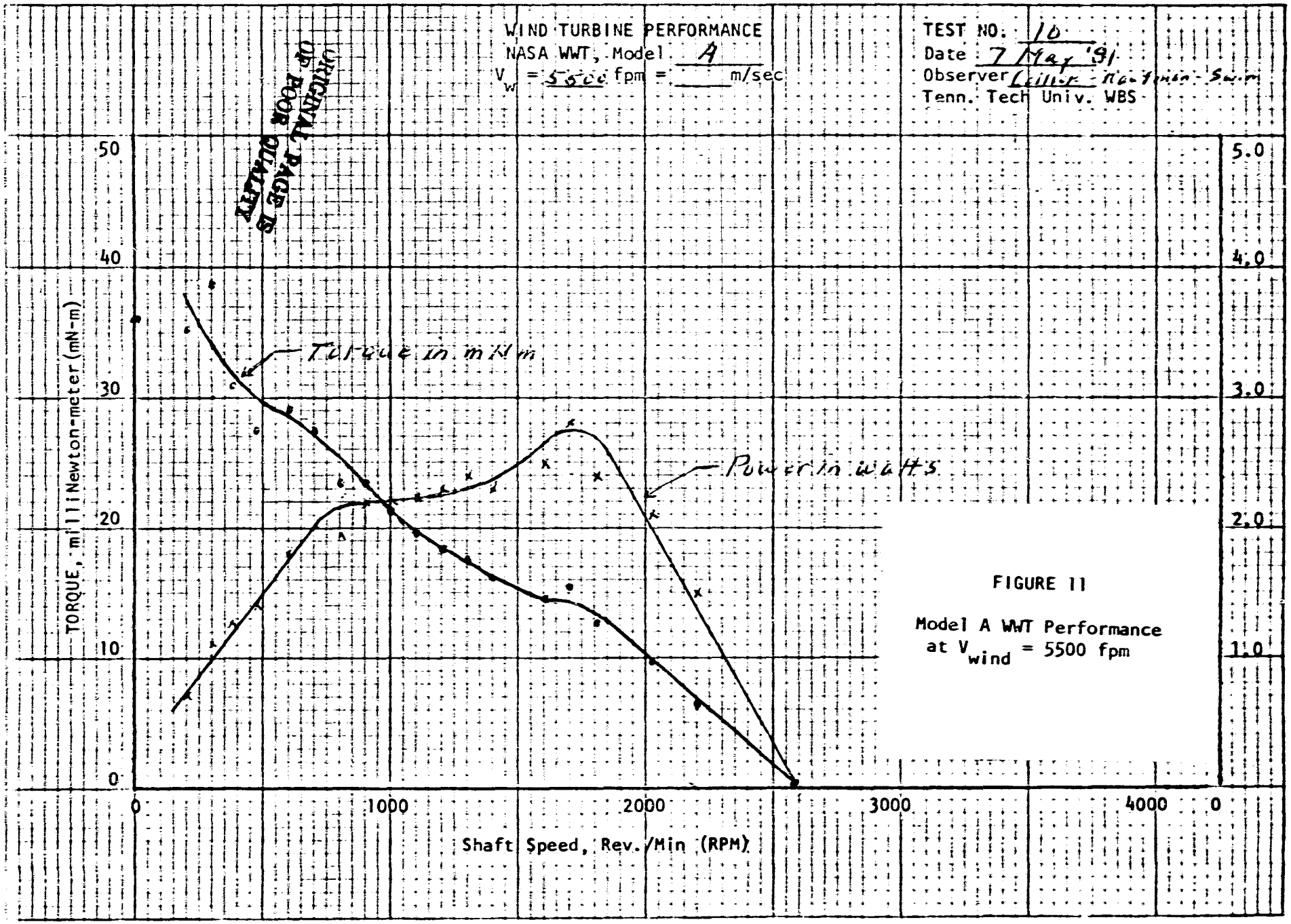


FIGURE 11

Model A WWT Performance at V_{wind} = 5500 fpm

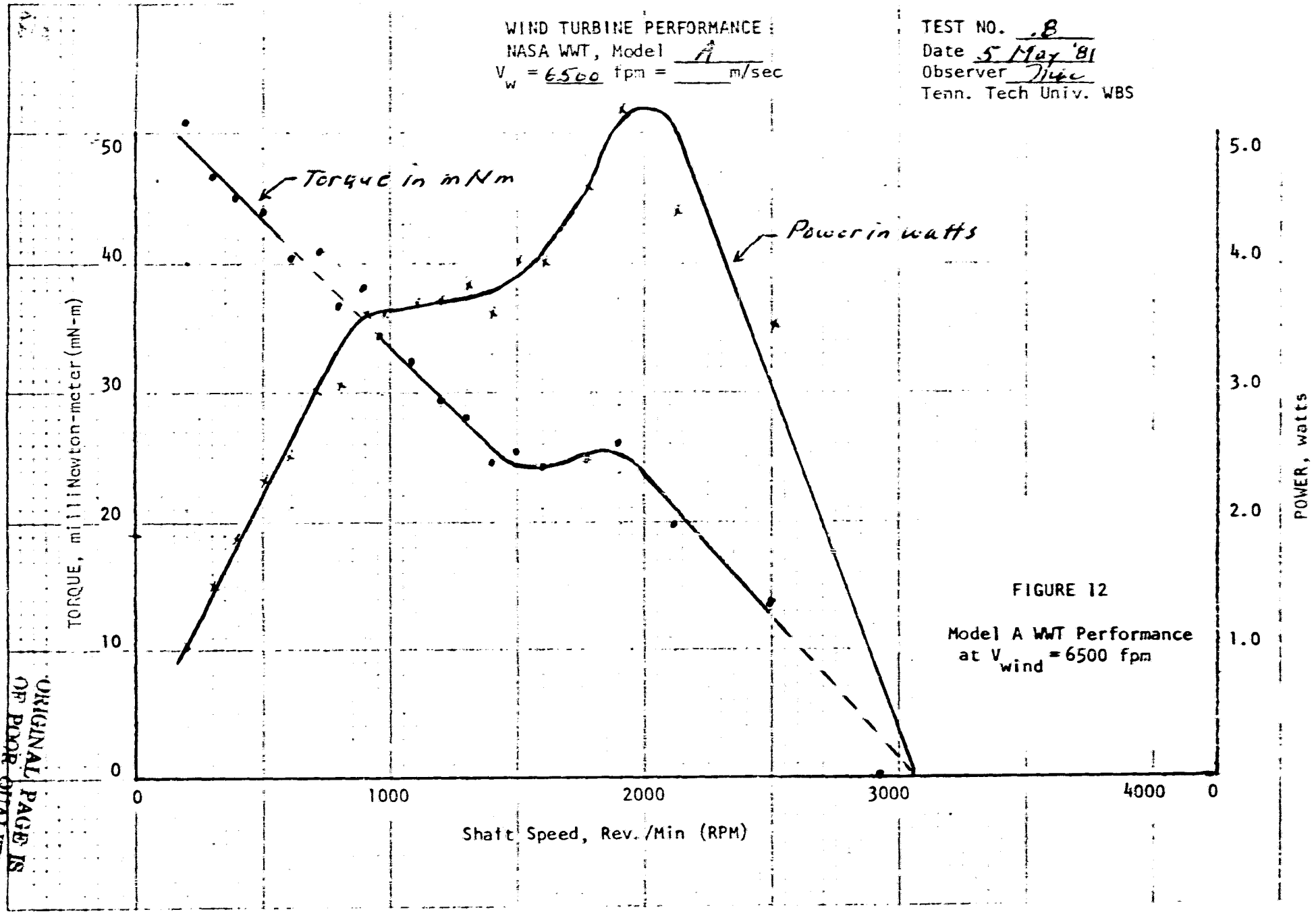


FIGURE 12

Model A WWT Performance at V_{wind} = 6500 fpm

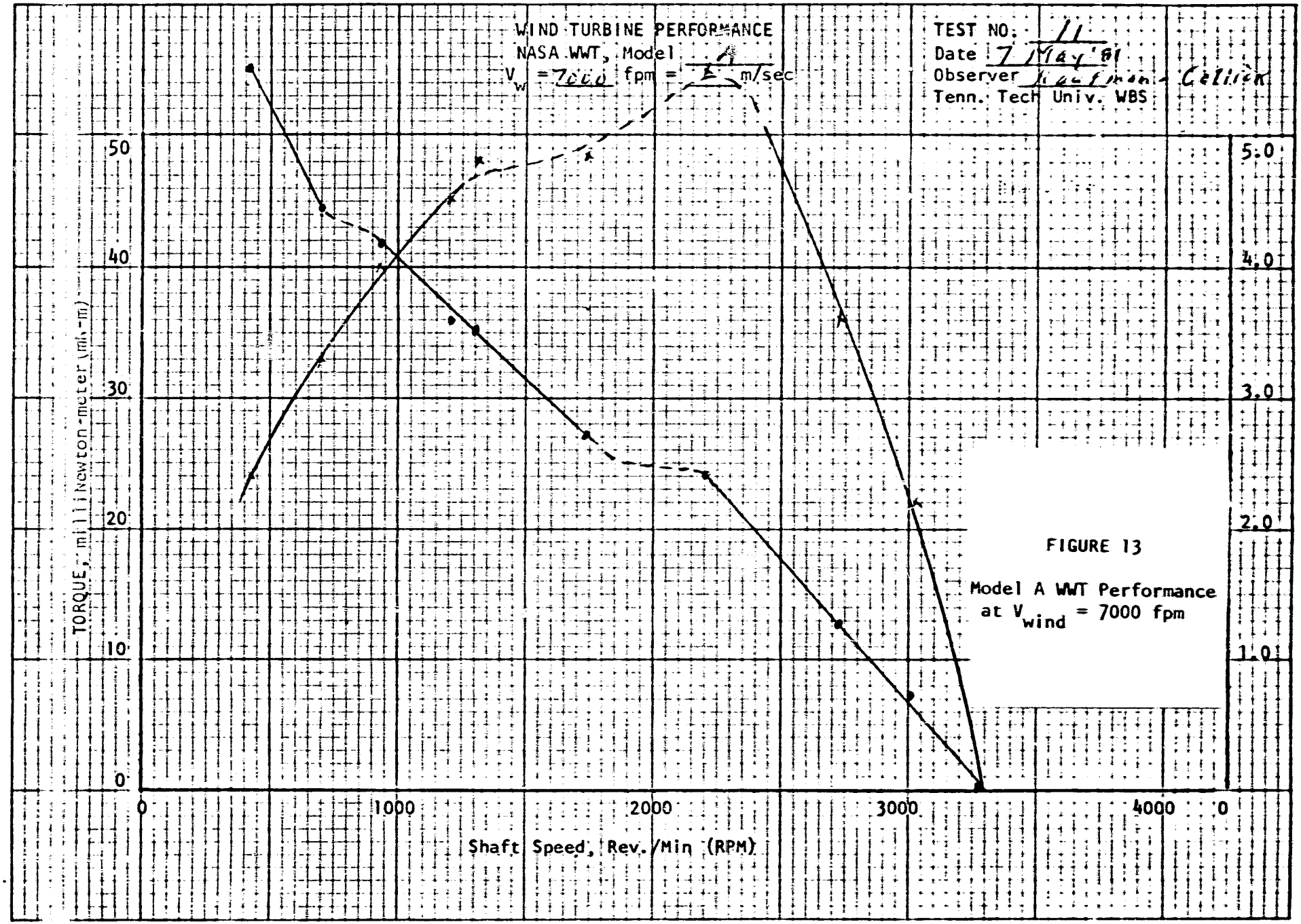


FIGURE 13

Model A WWT Performance at V_{wind} = 7000 fpm

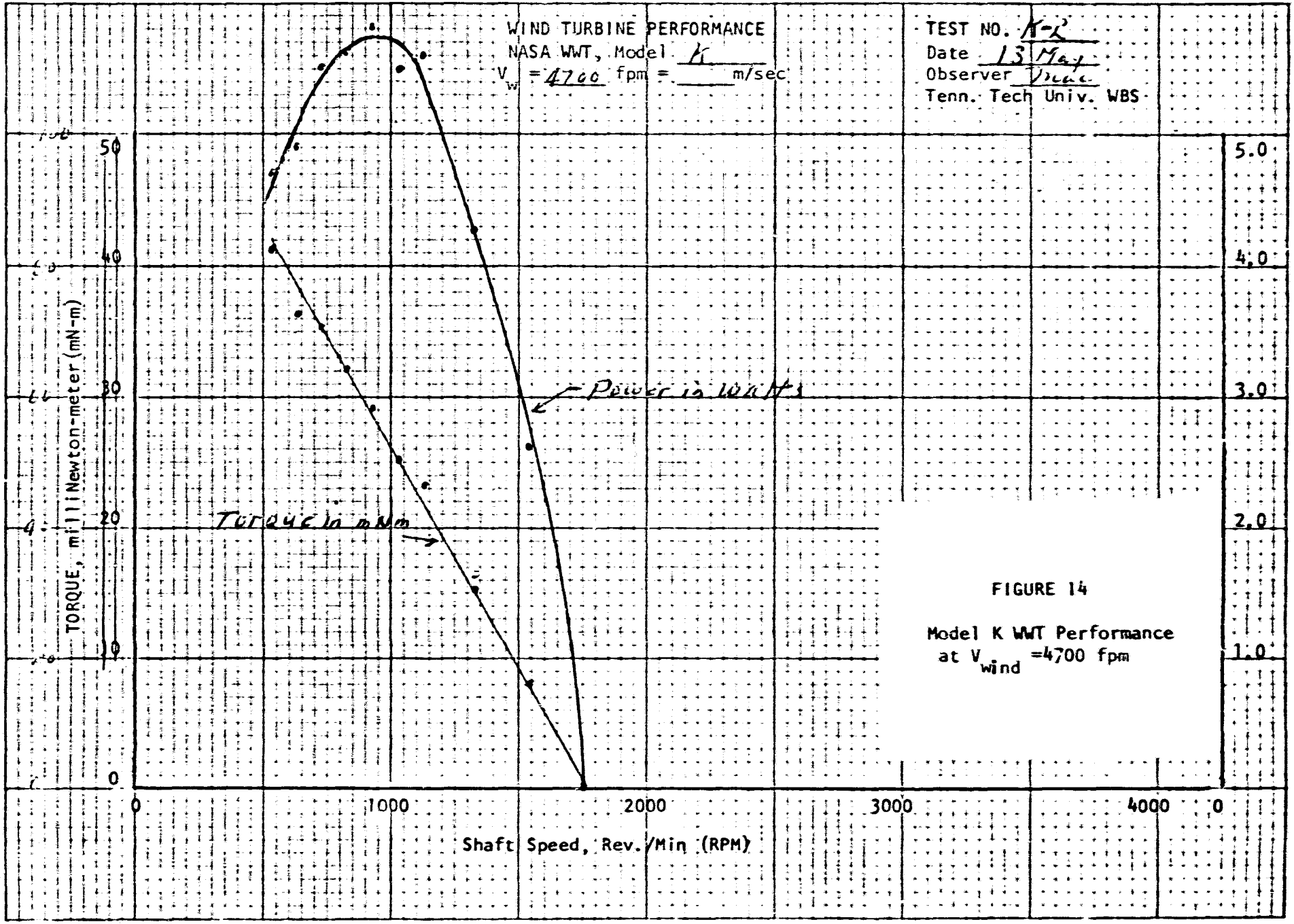


FIGURE 14

Model K WWT Performance at V_{wind} =4700 fpm

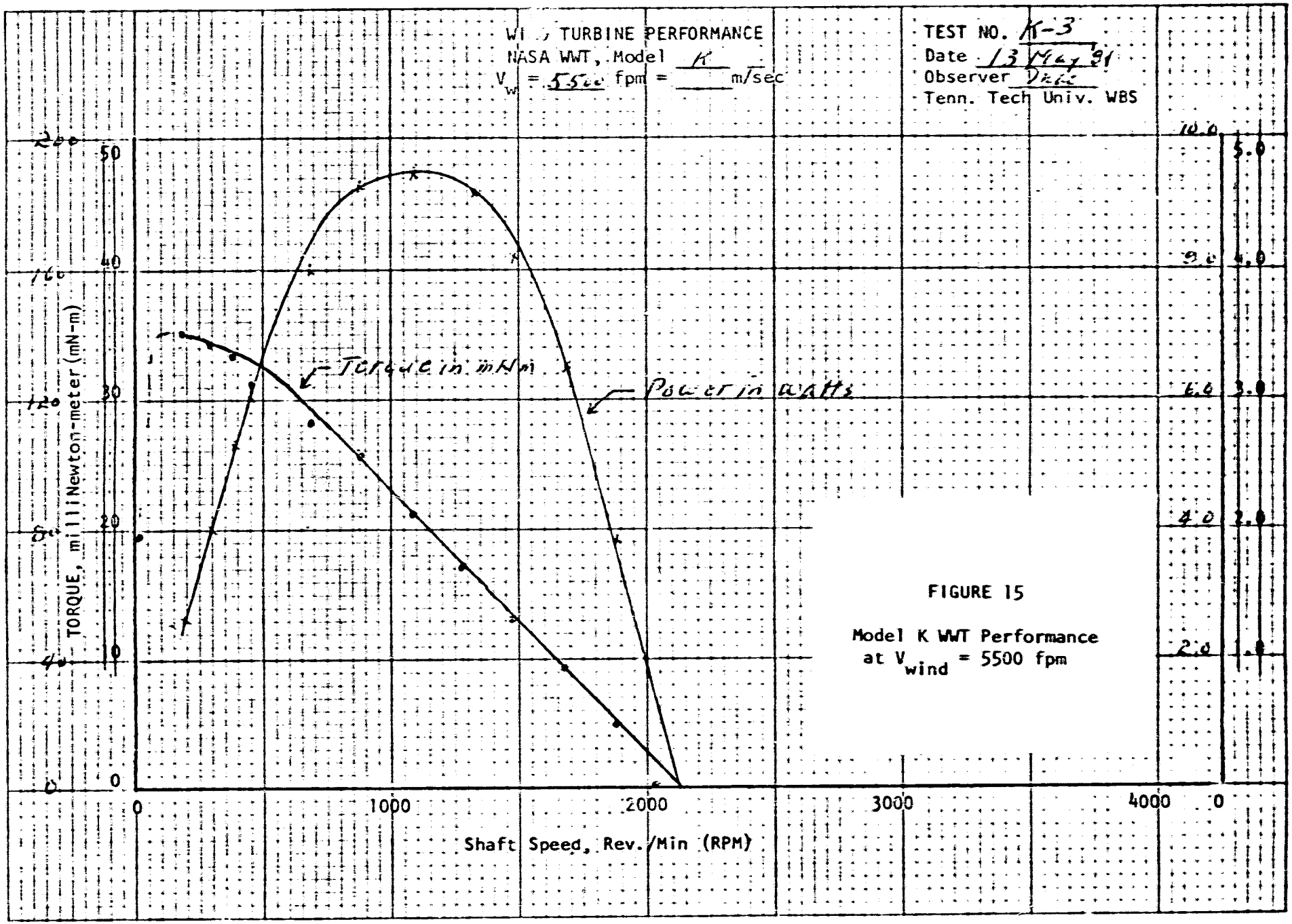


FIGURE 15

Model K WWT Performance
at V_{wind} = 5500 fpm

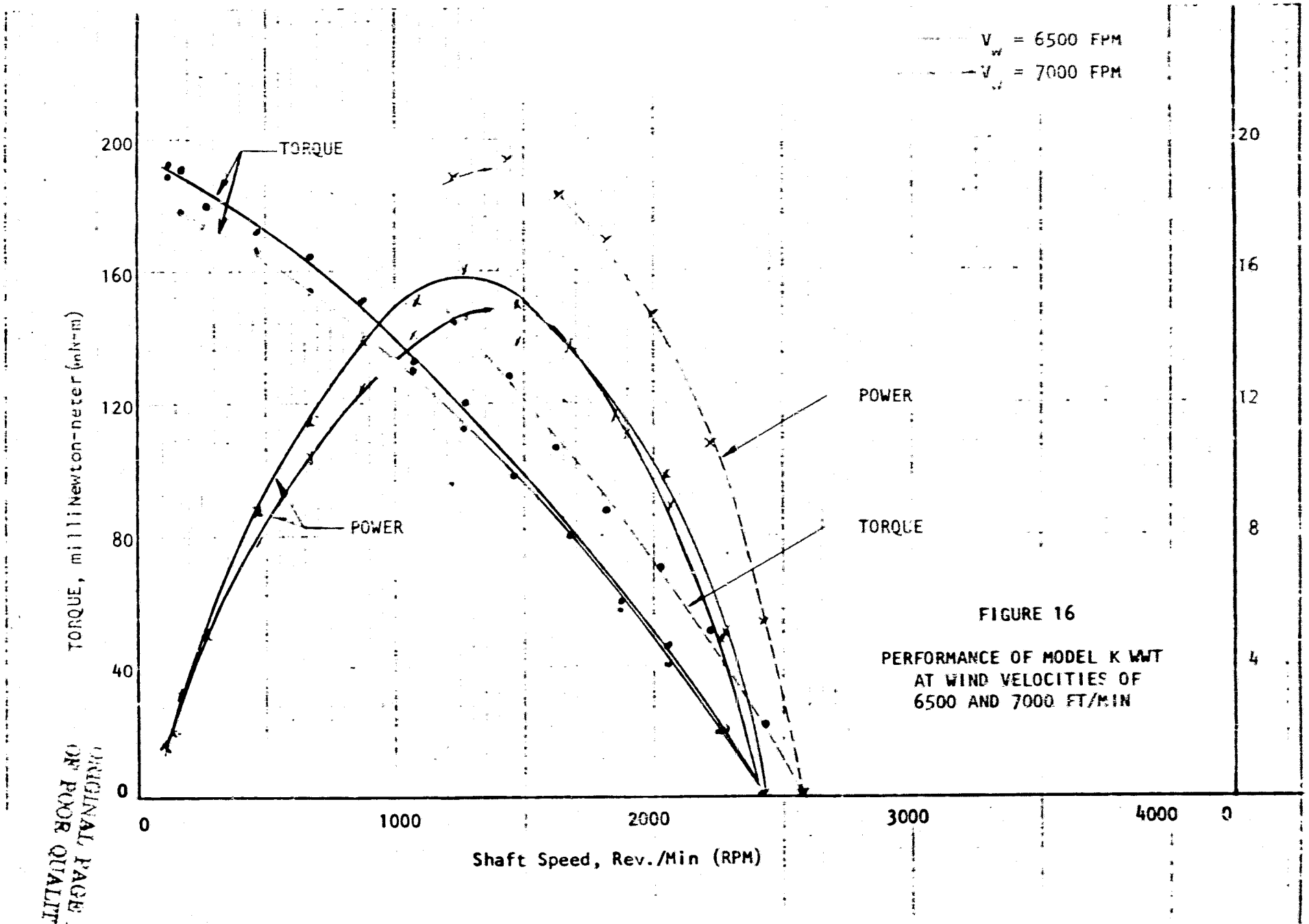
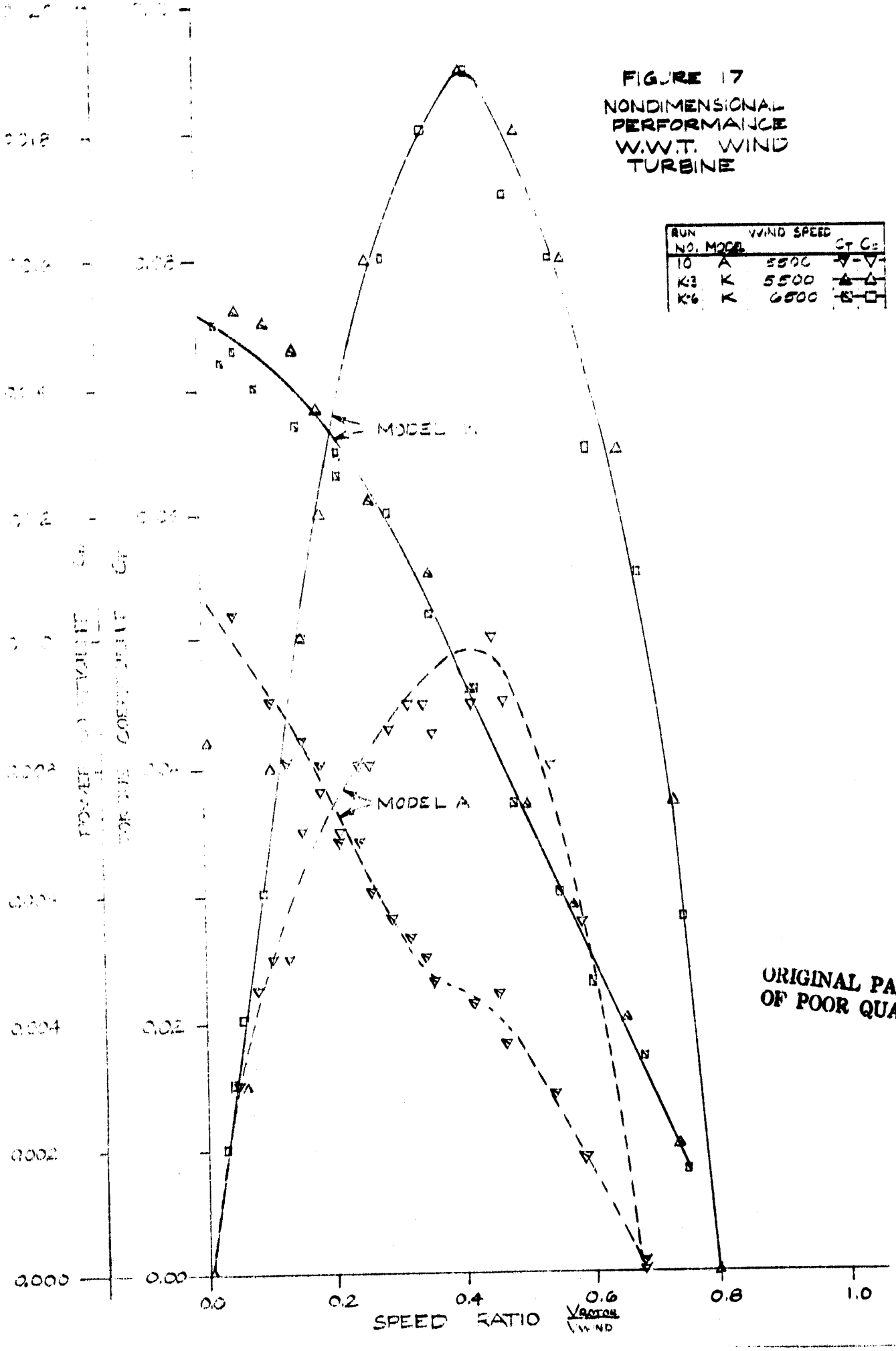


FIGURE 16

PERFORMANCE OF MODEL K WWT
AT WIND VELOCITIES OF
6500 AND 7000 FT/MIN



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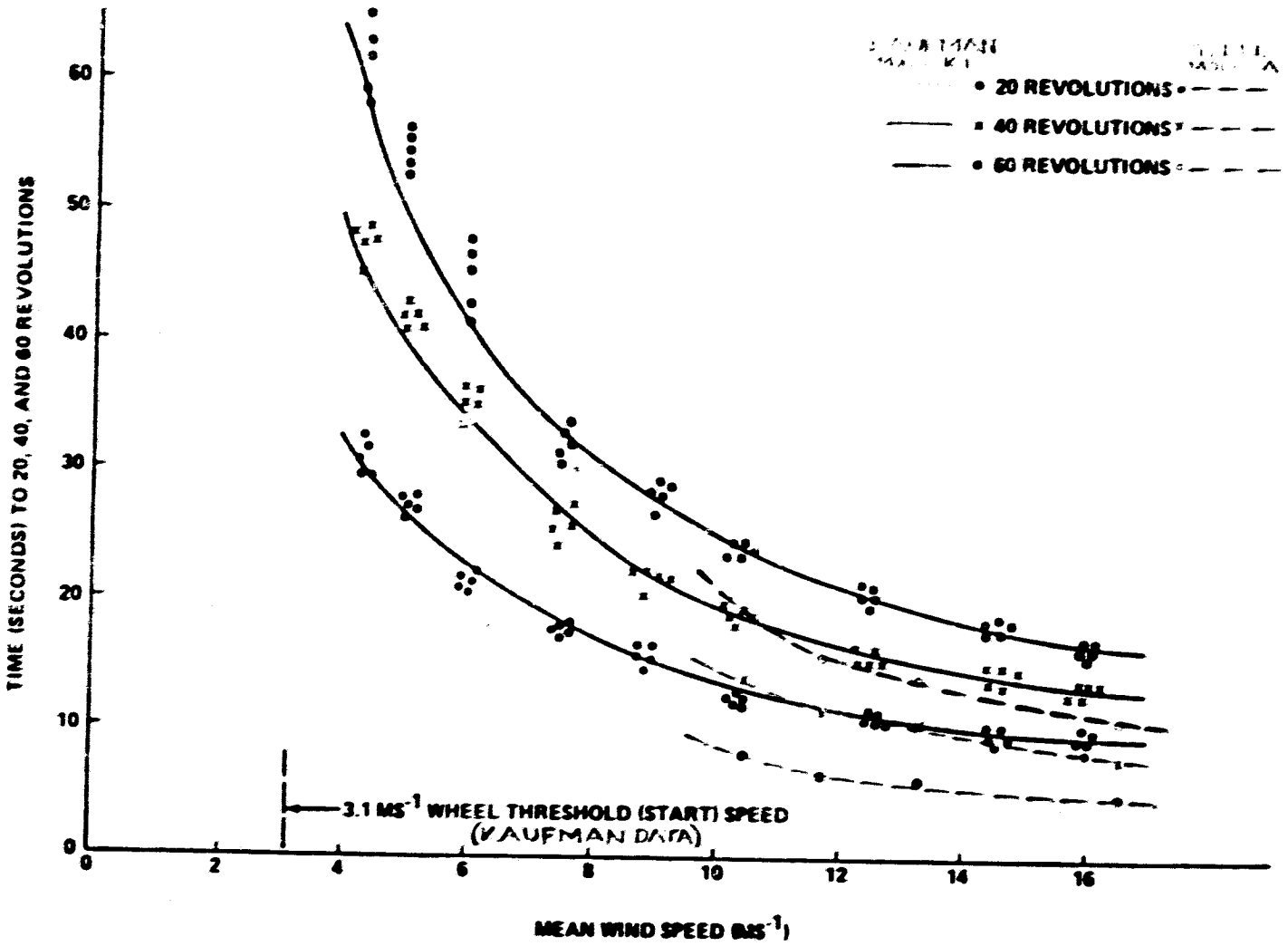


Figure 18 SPIN-UP TESTS - Time for WWT rotor to make 20, 40 and 60 revolutions versus mean wind speed

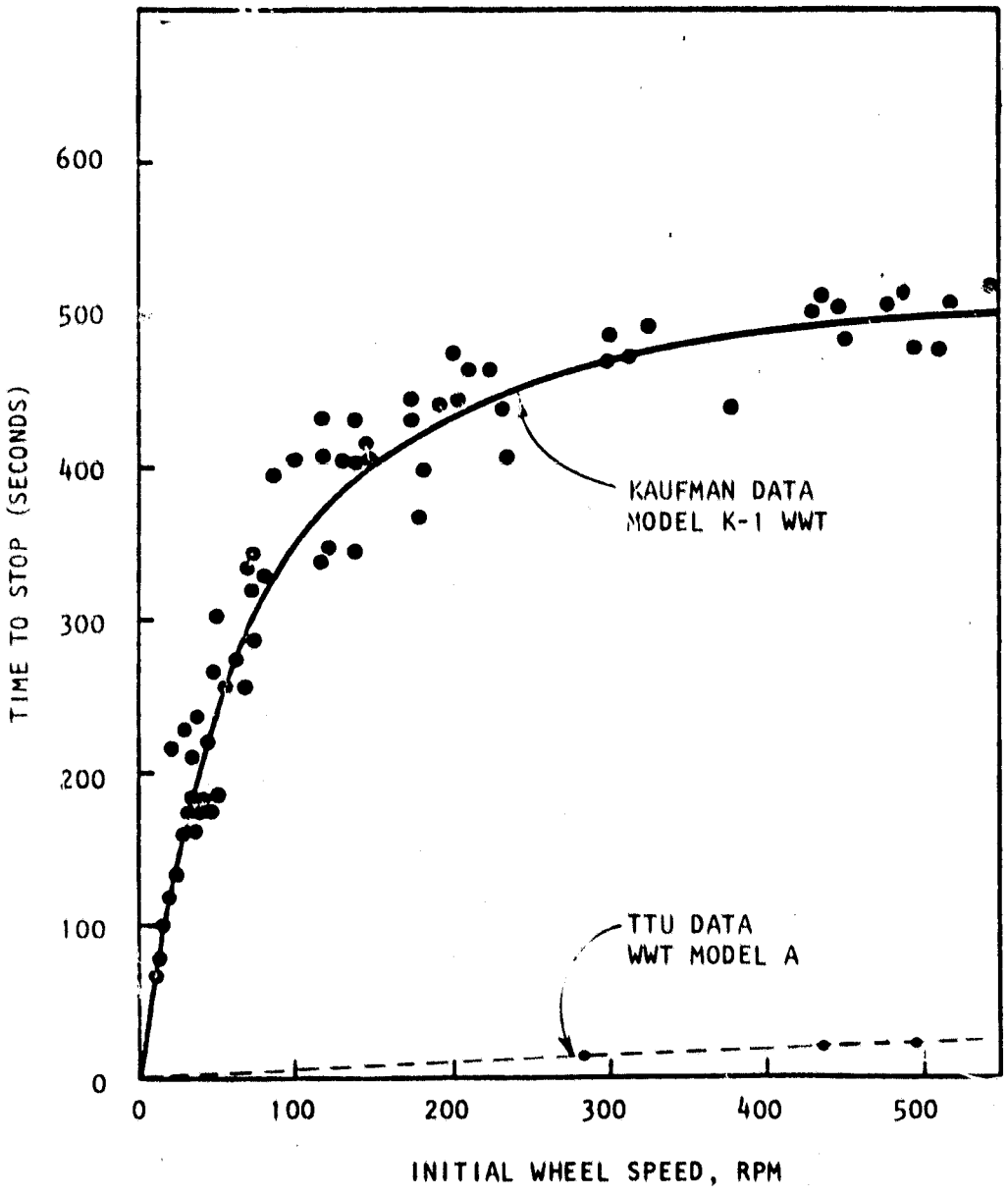


FIGURE 19 SPINDOWN TEST RESULTS

Time for WWT Rotor to stop versus initial rotor speed

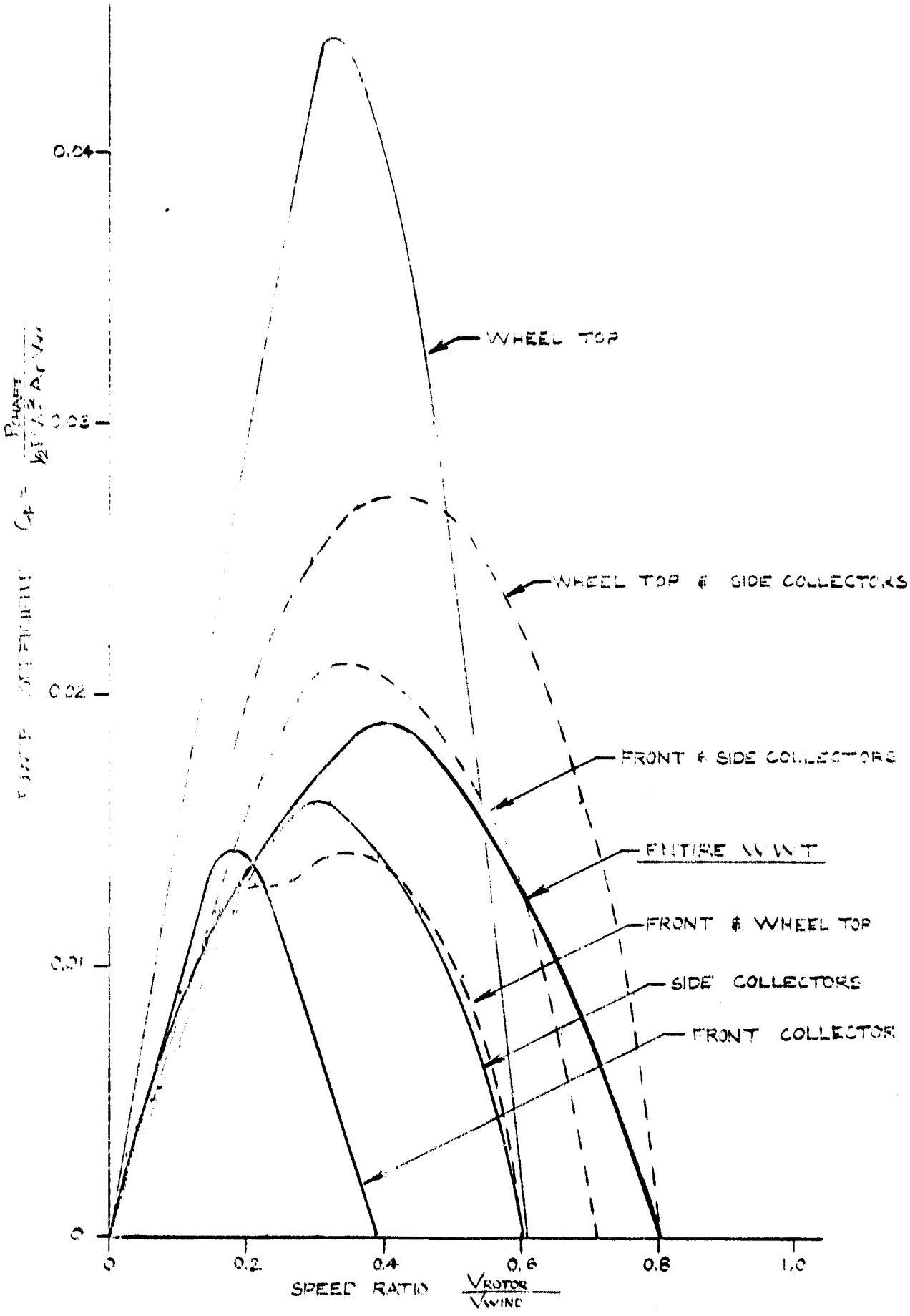


FIGURE 20 POWER COEFFICIENT FOR INDIVIDUAL WIND COLLECTOR SYSTEMS FOR MODEL K WWT
Based only on collector area open, V_{wind} = 6500 fpm

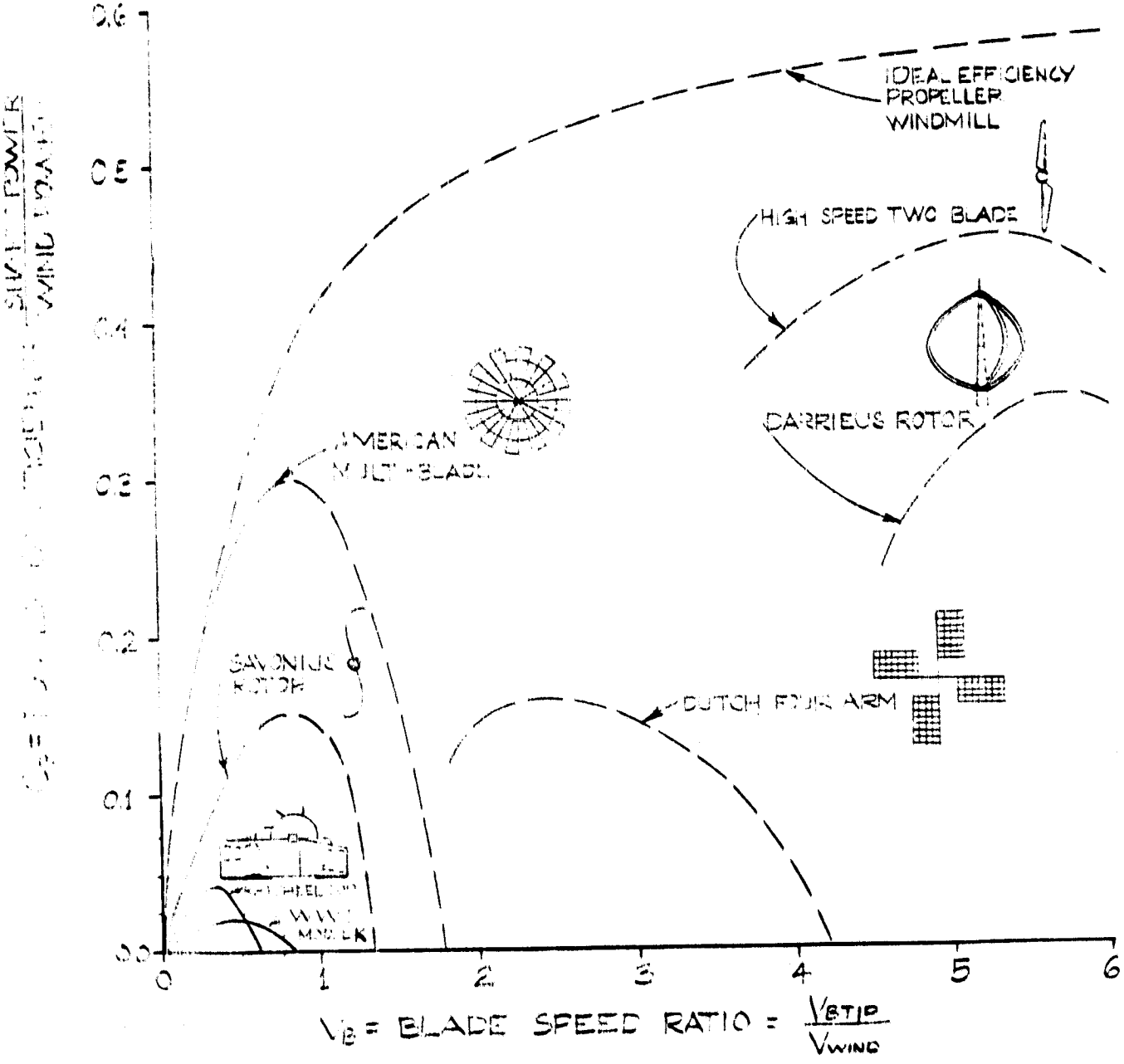


FIGURE 21 COMPARATIVE PERFORMANCE MAP
Power Coefficient Versus Speed Ratio

APPENDIX A
TEST DATA

Index of Data Sheets

Test No	Date	Model	Nominal Wind Speed ft/min	Description of Test
1	2/25/81	A	5500	Prony brake torque measurement
2	2/25/81	A	6500	" " " "
3	2/28/81	A	5500	Repeat of Test 1
4	3/2/81	A	6500	Repeat of Test 2
5	3/3/81	A	5500	Repeat of Test 1
6	3/4/81	A	6500	Repeat of Test 2
7	5/5/81	A	5500	Torquemeter readout
8	5/5/81	A	6500	" "
9	5/7/81	A	6500	" "
10	5/7/81	A	5500	Test with Kaufman
11	5/7/81	A	7000	Survey test with Kaufman
K-1	5/12/81	K	5500	Partial test - overloaded generator load
K-2	5/13/81	K	4700	Torquemeter readout, Friction brake load
K-3	5/13/81	K	5500	" " " " "
K-4	5/14/81	K	6500	" " " " "
K-5	5/22/81	K	4000	Stall torque tests
K-6	5/22/81	K	6500	Repeat of K-[illegible]
K-7	5/22/81	K	7000	Survey test only
K-8	6/19/81	K	5500	Side collectors only open
K-9	6/19/81	K	6500	" " " "
K-10	6/22/81	K	5500	Wheel top only open
K-11	6/22/81	K	6500	" " " "
K-12	6/22/81	K	5500	Front and wheel top open
K-13	6/22/81	K	6500	" " " " "
K-14	6/23/81	K	5500	Front inlet only open
K-15	6/23/81	K	6500	" " " "
K-16	6/23/81	K	5500	Front and side collectors open
K-17	6/23/81	K	6500	" " " " "
K-18	6/23/81	K	5500	Side collectors and wheel top open
K-19	6/24/81	K	6500	" " " " " "

Sheet 1 of 1

Test No. 1
Date 25 Feb. '86

TTU-NASA WWT TEST DATA

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) M. A. Curtis T$_{room}$ 75 °F; P$_{Bar}$ 29.26 "Hg; T$_{Bar}$ 25.0 °C
Dwyer 5:50 79 29.24 25.5

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.827	.95	90	2386	1.70			3.33	.83
	f		″	″	″	″	″				
2	s		1.824	.945	92	2269	2.60			5.10	1.21
	f		″	″	″	″	″				
3	s		1.819	.945	92	1966	5.30			10.40	2.14
	f		″	″	″	″	″				
4	s		1.819	.940	93	1810	6.50			12.74	2.41
	f		″	″	″	″	″				
5	s		1.815	.940	93	1657	8.05			15.80	2.74
	f		″	″	″	″	″				
6	s		1.811	.940	94	1515	9.50			16.70	2.65
	f		″	″	″	″	″				
7	s		1.809	.938	94	1255	8.40			16.46	2.16
	f		″	″	″	″	″				
8	s		1.809	.935	97	1121	9.55			18.72	~~3.68~~ 2.2
	f		″	″	″	″	″				
9	s		1.811	.945	97	946	11.20			21.95	2.17
	f		″	″	″	″	″				
10	s		1.809	.930	97	820	12.30			24.11	2.07
	f		″	″	″	″	″				
11	s		1.809	.935	97	700	13.10			25.67	1.88
	f		″	″	″	″	″				
12	s		1.809	.935	98	555	13.40			26.30	1.53
	f		″	″	″	″	″				
13	s		1.809	.935	98	447	14.55			28.52	1.33
	f		″	″	″	″	″				
14	s		1.809	.935	98	371	15.40			30.20	1.17
	f		″	″	″	″	″				
15	s		1.803	.935	98	245	16.60			32.53	.83
	f		″	″	″	″	″				
16	s		1.803	.935	98	158	~~16.60~~ 17.0			33.32	.55
	f		″	″	″	″	″				
17	s		1.803	.935	98	102	17.40			34.10	.36
	f		″	″	″	″	″				

COMMENTS: _____

Sheet 2

Test No. 1
Date 25 Feb. 81

TTU-NASA WWT TEST DATA

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} _____ °F; P_{Bar} _____ "Hg; T_{Bar} _____ °C

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
0	s		1.831	.900	90	2560	Arm removed				
X	f		″	″	″	″					
18	s		1.802	.935	98	54	17.40			34.10	.19
2	f		″	″	″	″	″				
19	s		1.802	.935	98	0	16.00			31.36	
3.	f		″	″	″	″	″				
20	s		1.802	.935	98	2554	Arm removed				
4.	f										
5	s										
	f										
6	s										
	f										
7	s										
	f										
8	s										
	f										
9	s										
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

TTU-NASA WWT TEST DATA

Date 2.5" Dia. Fan

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} 75 °F; P_{Bar} 29.22 "Hg; T_{Bar} 25.5 °C

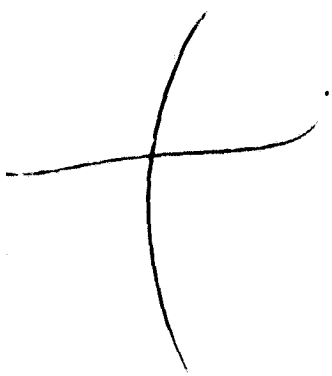
Dwyer 6500 -6400 cm

79 29.19 26.2

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.574	1.33	87	3020	Arm			0	
	f		2.565	1.35	"		removed				
2	s		2.554	1.32	91	2920	1.30			2.54	.78
	f		"	"	"	"	"				
3	s		2.544	1.32	96	2752	2.38			4.51	1.31
	f		"	"	"	"	"				
4	s		2.522	1.30	96	2466	4.25			8.33	2.30
	f		"	"	"	2466	"				
5	s		2.536	1.30	96	2486	5.6			11.0	2.86
	f		"	"	"	"	"				
6	s		2.533	1.30	96	2330	7.05			13.81	3.37
	f		"	"	"	"	"				
7	s		2.530	1.30	100	2172	9.0			17.64	4.01
	f		"	"	"	"	"				
8	s		2.519	1.30	100	2006	10.3			20.20	4.24
	f										
9	s		2.519	1.30	100	1854	11.7			22.93	4.45
	f										
10	s		2.519	1.30	101	1773	11.85			23.22	3.58
	f										
11	s		2.518	1.30	101	1543	11.60			22.73	3.67
	f		"	"	"	"	"				
12	s		2.518	1.30	101	1352	13.10			25.67	3.63
	f		"	"	"	"	"				
13	s		2.518	1.30	101	1139	15.00			29.40	3.51
	f		"	"	"	"	"				
14	s		2514	1.30	102	1029	16.35			32.04	3.45
	f		"	"	"	"	"				
15	s		2.514	1.30	102	830	18.1			35.50	3.08
	f		"	"	"	"	"				
16	s		2.514	1.30	105	764	18.25			35.80	2.86
	f		"	"	"	"	"				
17	s		2.505	1.30	105	612	18.60			36.50	2.34
	f		"	"	"	"	"				

COMMENTS: _____

			RPM	gr	Tor.	Wghs
2.505	1.30	105	502	18.85	36.90 —	1.94
2.505	1.30	"	402	18.80	36.85 —	1.55
2.505	1.30	"	302	19.30 —	37.83 —	1.19
2.510	1.30	"	204	19.65 —	38.51 —	.82
2.510	1.30	"	155	20.05 —	39.31 —	.64
2.510	1.30	"	115	21.80 —	42.73 —	.51
2.502	1.30	"	61	22.00 —	43.12 —	.27
2.501	1.30	"	40	22.80 —	44.69 —	.019
2.501	1.30	—	0	12.5 —	24.50 —	0
2.504	1.30	—	3010	Arm removed		



Date 2 FEB 82

TTU-NASA WWT TEST DATA

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} 72 °F; P_{Bar} 29.17 "Hg; T_{Bar} 23.5 °C

Dwyer .5500 - 5460 22 29.19 23.5

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.810	0.90	85	2501	0			0	0
	f		✓	✓	✓	✓					
2	s		1.801	0.90	85	2303	1.60			3.14	.76
	f										
3	s		1.787	0.90	85	2180	2.75			5.39	1.23
	f										
4	s		1.804	0.90	88	1975	4.55			8.92	1.84
	f										
5	s		1.797	0.88	88	1816	6.00			11.76	2.24
	f										
6	s		1.794	0.89	90	1654	8.00			15.68	2.72
	f										
7	s		1.790	0.91	93	1453	8.00			15.68	2.38
	f										
8	s		1.789	0.81	93	1233	8.30			16.27	2.10
	f										
9	s		1.779	0.87	93	1124	9.45			18.52	2.18
	f										
10	s		1.779	0.87	95	932	10.50			20.58	2.01
	f										
11	s		1.779	0.88	95	555	11.50			22.54	2.02
	f										
12	s		1.771	0.88	95	708	12.80			25.10	1.86
	f										
13	s		1.781	0.87	95	548	13.00			25.48	1.46
	f										
14	s		1.761	0.87	97	455	13.15			25.77	1.23
	f										
15	s		1.770	0.87	97	360	13.20			25.87	.97
	f										
16	s		1.775	0.87	97	249	13.30			26.07	.68
	f										
17	s		1.778	0.87	97	156	14.15			27.73	.45
	f										

COMMENTS: _____

T		
29.50	1.762	.081
30.19	1.773	.087
8.13	1.788	.067
	1.768	.087
	1.768	.087

rpm			P_2
104	15.05	97°	.32
57	15.40	97	.09

6	4.15	98 (6° pos on turbine
0	21.5?	" (blade 1/2 way)
2496	0	10° (540 on dwyer)

Position tried after making initial start test - suppose first suspected.

Test No. 47

Date 2 May 91

TTU-NASA WWT TEST DATA

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} 72 °F; P_{Bar} 29.15 "Hg; T_{Bar} 24.4 °C

Run 101 0500 - 6425 78 29.14 23.3

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.552	1.30	80	3004	0			0	0
	f										
2	s		2.542	1.30	87	2824	1.50			2.94	0.87
	f										
3	s		2.537	1.30	92	2624	3.20			6.30	1.66
	f										
4	s		2.531	1.30	90	2517	4.75			9.31	2.45
	f										
5	s		2.530	1.30	90	2522	4.45			8.72	2.30
	f										
6	s		2.509	1.30	92	2382	6.30			12.34	3.05
	f										
7	s		2.517	1.28	92	2275	7.45			14.60	3.48
	f										
8	s		2.516	1.27	93	2154	8.65			16.95	3.82
	f										
9	s		2.512	1.28	93	2002	10.20			19.99	4.19
	f										
10	s		2.485	1.27	95	1854	11.56			22.54	4.37
	f										
11	s		2.501	1.27	95	1742	11.10			21.75	3.97
	f										
12	s		2.506	1.26	98	1610	11.45			22.44	3.78
	f										
13	s		2.501	1.26	98	1505	11.50			22.54 ~~25.48~~	3.55
	f										
14	s		2.496	1.27	98	1348	13.00			25.48	3.60
	f										
15	s		2.495	1.26	99	1216	14.25			27.93	3.55
	f										
16	s		2.487	1.27	99	1055	15.90			31.16	3.44
	f										
17	s		2.487	1.27	99	918	17.00			33.32	3.20
	f										

COMMENTS: _____

Vol.	Sp	T.	[illegible]	[illegible]		T	P
2.477	1.27	100°	750	18.20		35.67	2.80
2.487	1.26	100°	604	18.45		36.16	2.29
2.483	1.26	100	506	18.75		36.75	1.95
2.482	1.26	100	349	19.70		38.61	1.41
2.482	1.26	100	212	21.20		41.55	0.92
2.480	1.26	101	110	22.10		43.31	0.50
2.475	1.27	101	55	22.30		43.70	0.25
2.475	1.27	101	0	6.2	→	12.15 [illegible]	0
2.471	1.28	101	2485	0			

Pos on drawing (can't get ink between - it locks over to 0)

10[illegible] Am [illegible]

Test No. 5
Date 3 March 91

TTU-NASA WWT TEST DATA

Performance Test of Model _____ WWT, Config. _____

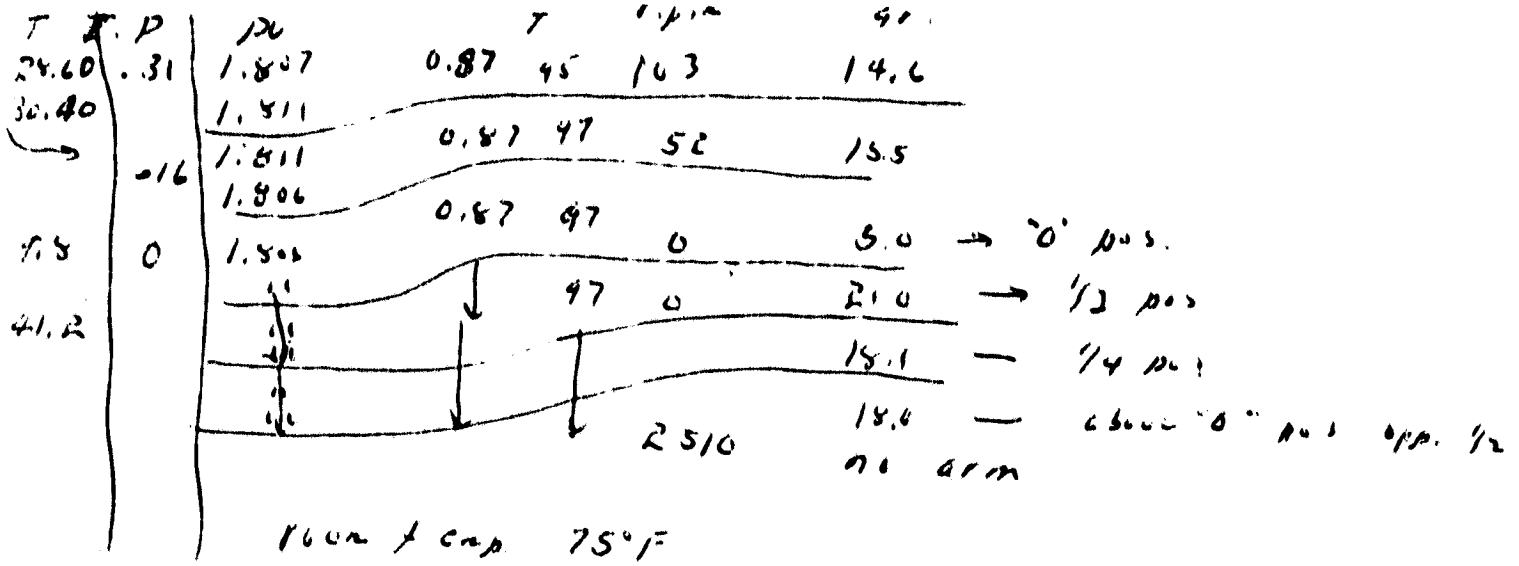
Test Objective _____

Test Cond. _____

Observer(s) Jim, A. Parker T_{room} 72 °F; P_{Bar} 29.26 "Hg; T_{Bar} 24.3 °C

Dwyer: 5500 - 5500 75 29.22 24.8

Data Pt. No.		Time (were up 15 min)	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	9:45	1.847	0.90	85	2564	0	5586	28.39	0	0
	f		1.847	0.90							
2	s		1.826	0.90	86	~~2286~~ 2345	2.15	5544	28.27	4.21	1.03
	f		1.832								
3	s		1.834	0.90	88	2206	3.00	5590	28.40	5.89	1.35
	f		1.817								
4	s		1.817	0.90	88	2004	4.80	5556	28.28	9.41	1.97
	f										
5	s		1.839	0.90	89	1610	6.20	5595	28.42	12.15	2.30
	f										
6	s		1.836	0.90	90	1643	7.90	5574	28.32	15.48	2.66
	f		1.814								
7	s		1.832	0.90	90	1410	8.10	5566	28.28	15.87	2.34
	f		1.829								
8	s		1.823	0.90	92	1285	8.20	5593	28.37	16.10	2.17
	f		1.819								
9	s		1.812	0.90	92	1138	9.25	5568	28.30	18.13	2.16
	f		1.812								
10	s		1.812	0.90	92	950	10.50	5569	28.30	20.60	2.05
	f		1.812								
11	s		1.812	0.90	93	828	12.00	5575	28.33	23.52	2.04
	f		1.811								
12	s		1.811	0.90	93	700	13.00	5574	28.32	25.50	1.87
	f		1.811								
13	s		1.811	0.90	93	547	13.35	5577	2834	26.20	1.50
	f		1.811								
14	s		1.811	0.87	95	458	13.35	5586	28.36	26.20	1.28
	f		1.806								
15	s		1.806	0.87	95	347	13.70	5579	28.35	26.85	0.98
	f		1.806								
16	s		1.806	0.87	95	242	13.90	5576	28.33	27.05	0.68
	f		1.802								
17	s		1.807	0.87	95	149	14.50	5582	28.31	28.42	0.44
	f		1.812								



Room temp 75°F

Test ended 11:05

Data Point	V_{tu} Ft/min	V_{tu} m/s
18	5582	28.37
19	5544	28.42
20	5584	28.40

Test No. 6

Nom. Wind Vel. 6500 - 6400

Date 4/16/85

TTU-NASA WWT TEST DATA

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) B. A. Cochran T_{room} 72 °F; P_{Bar} 28.94 "Hg; T_{Bar} 24.2 °C

Dayton 6500 - 6400 time start 8:35 end 10:10

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	8:35	2.557	1.30	85	3012	0			0	0
	f		2.554								
2	s		2.542	1.30	88	2755	2.5	6611	33.59	4.90	1.41
	f		2.552								
3	s		2.534	1.30	88	2617	4.25			8.33	2.28
	f		2.545								
4	s		2.542	1.30	91	2450	5.80	6623	33.66	11.37	2.92
	f										
5	s		2.523	1.30	91	2312	7.40			14.50	3.51
	f		2.529								
6	s		2.533	1.30	93	2150	9.20			18.03	4.06
	f		2.518								
7	s		2.508	1.30	93	2001	10.80	6586	33.47	21.17	4.43
	f		2.503								
8	s		2.520	1.30	93	1804	11.60			22.74	4.30
	f		2.525								
9	s		2.512	1.28	97	1708	11.45			22.40 ~~2.40~~	4.00
	f		2.512								
10	s		2.512	1.28	97	1501	11.60	6609	33.56	22.73	3.57
	f		2.504								
11	s		2.506	1.28	97	1402	12.40			24.30	3.57
	f		2.506								
12	s		2.506	1.28	97	1250	14.10	6597	33.53	27.64	3.62
	f		2.500								
13	s		2.506	1.28	100	1104	15.40			30.20	3.49
	f		2.498								
14	s		2.506	1.28	100	947	16.90	6608	33.56	33.12	3.28
	f		2.492								
15	s		2.498	1.28	100	853	18.00 ~~16.80~~			35.30	3.15
	f		2.497								
16	s		2.497	1.28	100	706	18.70			36.70	2.71
	f		2.497								
17	s		2.499	1.28	100	559	19.10	6609	33.56	37.44	2.19
	f		2.494								

COMMENTS: _____

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H$_2$O	Static Press P_s "H$_2$O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		2.494	1.28	102	440	19.50			38.22	1.76
	f		2.501								
19	s		2.496	1.28	102	339	20.06			39.20	1.39
	f		2.493								
20	s		2.493	1.28	102	203	21.70			42.53	0.90
	f		2.493								
21	s		2.497	1.28	102	105	22.30			43.71	0.48
	f		2.485								
22	s		2.495	1.28	102	53	22.60			44.30	0.25
	f		2.496								
23	s		2.490	1.28	102	0	7.20			14.11	0
	f										
24	s			1.28	102	0	32.0			62.72	0
	f										
25	s	10:10	2.496	1.28	102	~~2997~~	25.7			50.37	0
	f										
26	s		2.496	1.28	102	2997	0			0	
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 77 °F, P_{Bar} 28.91 "H$_2$O, T_{Bar} 24.2 °C, Time 10:10

COMMENTS: _____

Test No. 7

Nom. Wind Vel. 5500 fpm

Date 5th May E

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT. Config. S/S. - As per Drawing

Test Objective

Test Cond.

Observer(s) [illegible] T_{room} 76 °F; P_{Bar} 29.11 "Hg; T_{Bar} 22.5 °C

time start 12:30 end 1:33

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H₂O	Static Press P_S "H₂O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	12:30	1.824				No Load				
	f		1.844	.94	82	2424				0	0
2	s										
	f		1.824	.94	90	2221	0.8			5.65	1.31
3	s										
	f		1.816	.94	90	2019	1.4			9.88	2.09
4	s										
	f		1.812	.94	90	1813	1.8			12.71	2.41
5	s										
	f		1.812	.94	90	1701	2.3			16.24	2.89
6	s										
	f		1.809	.94	90	1610	2.3			16.24	2.74
7	s										
	f		1.809	.93	93	1483	2.6			18.36	2.85
8	s										
	f		1.801	.93	93	1393	2.3			16.24	2.37
9	s										
	f		1.802	.91	93	1297	2.4			16.95	2.30
10	s										
	f		1.802	.91	93	1180	2.6			18.36	2.27
11	s										
	f		1.802	.91	93	1074	2.8			19.77	2.22
12	s										
	f		1.802	.91	94	1001	3.0			21.18	2.22
13	s										
	f		1.797	.91	94	896	3.2			22.45	2.11
14	s										
	f		1.797	.91	95	797	3.6			25.41	2.12
15	s										
	f		1.797	.91	95	693	3.8			26.83	1.95
16	s										
	f		1.797	.91	95	623	3.8			26.83	1.75
17	s										
	f		1.797	.91	95	502	3.8			26.83	1.41

COMMENTS: No Load is mechanical friction of motor/gen only, brushes UP

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H$_2$O	Static Press P_s "H$_2$O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		1.797	.91	95	400	4.1			28.95	1.21
	f										
19	s		1.797	.91	95	349	4.7			33.18	1.21
	f										
20	s	1.33	1.797	.91	95	246	4.8			33.89	.87
	f										
21	s						Stall*				
	f										
22	s					2428	No Load				
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 77 °F, P_{Bar} 29.07 "Hg, T_{Bar} 23.0 °C, Time 1,33

COMMENTS: * 1,8 - 4.0 - 0.5 - 2.1 - 3.1 appear some variation when wheel was indexed

Test No. 8.0
Nom. Wind Vel. 65.00 f/m
Date 5 May 81

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) M. A. Cuevas T_{room} 78 °F; P_{Bar} 29.06 "Hg; T_{Bar} 23.0 °C

time start 2:45 end 3:57

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	2:45	2.593	.33	85	2998	No Load			0	0
	f										
2	s		2.590	.35	85	2502	1.9			13.41	3.51
	f										
3	s		2.591	35	95	~~2012~~ 2121	2.8			19.77	4.41
	f										
4	s		2.593	.35	95	1894	3.7			26.12	5.18
	f										
5	s		2.593	.35	95	1772	~~3.4~~ 3.5			24.71	4.58
	f										
6	s		2.577	.35	95	1612	3.4			24.00	4.05
	f										
7	s		2.557	.35	98	1497	3.6			25.41	3.98
	f										
8	s		~~2.575~~ 2.576	.35	100	1396	3.5			24.71	3.61
	f										
9	s		2.573	.35	100	1291	4.0			28.24	3.82
	f										
10	s		2.573	.35	100	1201	4.2			29.65	3.72
	f										
11	s		2.559	.35	100	1084	4.6			32.48	3.68
	f										
12	s		2.559	.35	100	986	4.9			34.60	3.57
	f										
13	s		2.562	.35	100	898	5.4			38.13	3.58
	f										
14	s		2.560	.35	100	800	5.2			36.72	3.07
	f										
15	s		2.554	.35	100	725	5.8			40.95	3.11
	f										
16	s		2.554	.35	100	594	5.7			40.24	2.50
	f										
17	s		2.554	.35	103	499	6.2			43.78	2.29
	f										

COMMENTS: No load is mechanical friction of motor/gen. only, brushes UP

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H$_2$O	Static Press P_s "H$_2$O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		2.566	.35	103	400	6.4			45.19	1.89
	f										
19	s		2.556	.35	103	303	6.6			46.60	1.48
	f										
20	s		2.556	.35	103	195	7.2			50.84	1.04
	f										
21	s						Stall 5.35 *			37.78	0
	f										
22	s					2986	No Load			~~37.78~~	
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{Room} 68 °F, P_{Bar} 29.04 "H_2O, T_{Bar} 23.5 °C, Time 3:57

COMMENTS: * 5.1 - 4.3 - 2.6 - 5.3 - 6.7 - 3.3 - 4.7 62/in Stall
Range - Ave.

Test No. 9
Nom. Wind Vel. 6500
Date 7 May '81

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. Std. - As per Drawing

Test Objective

Test Cond.

Observer(s) M. A. Cuevas T_{room} 76 °F; P_{Bar} 29.69 "Hg; T_{Bar} 19.5 °C

time start 9:15 end 9:35

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.586	.33	84	3053	0			0	0
	f										
2	s		2.588	.33	84	2570	1.2			8.47	2.30
	f										
3	s		2.556	.33	84	2062	2.8			19.77	4.31
	f										
4	s		2.572	.33	87	1852	3.4			24.00	4.68
	f										
5	s		2.569	.33	87	1733	3.1			21.89	3.97
	f										
6	s		2.565	.33	88	1615	3.3			23.30	3.94
	f										
7	s		2.563	.33	88	1497	3.2			22.59	3.54
	f										
8	s		2.560	.33	88	1404	3.7			26.12	3.85
	f										
9	s		2.555	.33	91	1305	3.9			27.54	3.76
	f										
10	s		2.552	.33	91	1203	4.3			30.36	3.82
	f										
11	s		2.547	.30	91	1052	4.6			32.48	3.71
	f										
12	s		2.541	.30	92	996	4.6			32.48	3.39
	f										
13	s		2.541	.31	92	897	5.0			35.30	3.32
	f										
14	s		2.541	.31	92	804	5.5			38.84	3.27
	f										
15	s		2.541	.30	92	701	5.3			37.42	2.75
	f										
16	s		2.541	.31	92	599	5.2			36.72	2.30
	f										
17	s		2.541	.32	93	502	5.7			40.25	2.12
	f										

COMMENTS: Brake was pulled manually until

until read out shows "0" torque.

Nom. Wind Vel. 6500 fpm

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s f		2.541	.31	93	319	6.5			45.90	1.92
19	s f		2.541	.31	93	312	6.5			49.01	1.57
20	s f		2.541	.31	93	203	7.0			49.43	1.05
21	s f						Stall				
22	s f					3068	No Load				
23	s f										
24	s f										
25	s f										
26	s f										
27	s f										
28	s f										
29	s f										
30	s f										
31	s f										
32	s f										
33	s f										
34	s f										

Final Room Data: T_{room} 73 °F, P_{Bar} 29.09 "H_2O, T_{Bar} 19.5 °C, Time 9:35

COMMENTS: _____

Test No. 10
Nom. Wind Vel. 5 500
Date 7 May '8

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. STD - As per Drawing

Test Objective Torque-Speed Curve.

Test Cond.

Observer(s) Collick, Kaufman, Smith T_{room} 71.5 °F; P_{Bar} 29.09 "Hg; T_{Bar} 19.0 °C

time start 1:35 end 2:17

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	1:27P	1.820	.90	78	2584	~~2584~~ 0			0	0
	f										
2	s		1.790	.90	78	2209	0.90			6.35	1.47
	f										
3	s		1.807	.92	81	2029	1.4			9.89	2.10
	f										
4	s		1.799	.92	81	1811	1.8			12.71	2.41
	f										
5	s		1.797	.91	83	1707	2.2			15.53	2.78
	f										
6	s		1.797	.91	83	1605	2.1			14.83	2.49
	f										
7	s		1.793	.91	83	1400	2.3			16.24	2.30
	f										
8	s		1.790	.90	83	1298	2.5			17.65	2.40
	f										
9	s		1.790	.90	83	1212	2.6			18.36	2.33
	f										
10	s		1.787	.90	83	1095	2.8			19.17	2.27
	f										
11	s		1.787	.90	86	993	3.6			~~21.88~~ 21.19	2.20
	f										
12	s		1.787	.90	86	904	3.3			23.30	2.21
	f										
13	s		1.787	.90	86	803	3.3			23.30	1.91
	f										
14	s		1.787	.90	86	703	3.9			27.54	2.03
	f										
15	s		1.787	.90	86	602	4.1			28.95	1.82
	f										
16	s		1.787	.90	86	~~494~~ 486	~~4.~~ 3.9			27.54	1.40
	f										
17	s		1.787	.90	86	392	4.4			31.07	1.28
	f										

COMMENTS: No Load obtained same as in Test 9, 7 May. Motor boost r.p.m. until readout gave "0" torque

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ OZ/Fin gm	Velocity V_w fpm	m/s	Torque T mN·m	Power P Watts
18	s f		1.787	.90	86	197	5.5			38.84	1.21
19	s f		1.783	.90	86	196	5.0			35.31	0.72
20	s f					0	Still				
21	s f		0° pos of blade:								
22	s f		5.2 - 0.6 - 3.5 0.8 - 2.5 - 2.1			245					
23	s f		1/2 pos of blade								
24	s f		6.0 - 6.4 - 7.3 6.2 - 6.8 - 6.7			6.56					
25	s f		1/4 pos of blade								
26	s f		6.0 - 6.2 - 5.4 5.4 - 6.3 - 6.0			5.83					
27	s f		3/4 pos of blade								
28	s f		5.3 - 5.6 - 6.2 5.7 - 5.7 - 5.1			5.6	Ave. 5.12			36.17	
29	s f										
30	s f										
31	s f										
32	s f										
33	s f										
34	s f										

Final Room Data: T_{room} 72.0 °F, P_{Bar} 29.9 ~~"H_2O~~ "Hg, T_{Bar} 18.0 °C, Time ~~7:20~~ 2:17

COMMENTS: _____

Test No. 11 ⊗
Nom. Wind Vel. 7000 fpm
Date 7 May

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. Std. as per Drawing

Test Objective

Test Cond.

Observer(s) Kaufman - Collett T_{room} °F; P_{Bar} "Hg; T_{Bar} °C
time start 3:30 end 3:45 $P_{Bar_{corr}}$ "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) Arm) oz/fin gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		—	—	85	3277	0			0	0
	f										
2	s					3069	1.0			7.1	2.24
	f										
3	s					2734	1.8			12.71	3.64
	f										
4	s					2197	3.4			24.00	5.52
	f										
5	s					1733	3.8			26.83	4.87
	f										
6	s					1297	5.0			35.31	4.79
	f										
7	s					1192	5.1			36.01	4.49
	f										
8	s					928	5.9			41.66	4.04
	f										
9	s					704	6.3			44.48	3.28
	f										
10	s					412	7.8			55.08	2.37
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: ⊗ Survey Test - Not intended to be Complete
Motor boost r.p.m. until readout gave "0" torque

Test No. 11-1

Nom. Wind Vel. 5500

Date 12 May

TTU-NASA WWT TEST DATA

Performance Test of Model K WWT, Config. Alum. Model by NASA

Test Objective

Test Cond.

Observer(s) M. A. Collier T_{room} 65 °F; P_{Bar} 29.64 "Hg; T_{Bar} 15.5 °C

time start 1116 end 1135 $P_{Bar_{corr}}$ same "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s/f		1.833	.83	76	2063	0			0	0
2	s/f		1.824	.83	78	1871	2.7			19.06	3.73
3	s/f		1.815	.83	78	1655	5.2			36.7	6.36
4	s/f		1.815	.83	78	1464	7.4			52.25	8.00
5	s/f		1.806	.83	78	1357	8.6			60.72	8.64
6	s/f		1.806	.83	82	1263	9.7			68.49	9.05
7	s/f		1.806	.83	82	1178	10.8			76.26	9.40
8	s/f										
9	s/f										
10	s/f										
11	s/f										
12	s/f										
13	s/f										
14	s/f										
15	s/f										
16	s/f										
17	s/f										

COMMENTS: Too much load for generator - overheats in Buck pos.

Nom. Wind Vel. 5500 fpm
Date 12 May '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s						/				
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} ____ °F, P_{Bar} 29.24 "Hg, T_{Bar} 15.5 °C, Time 1735

COMMENTS: _____

Test No. K-2
Nom. Wind Vel. 4700
Date 13 May 81

TTU-NASA WWT TEST DATA

Performance Test of Model K WWT, Config. Alum. Model by NASA

Test Objective _____

Test Cond. _____

Observer(s) M. A. Cline T_{room} 63 °F; P_{Bar} 29.20 "Hg; T_{Bar} 17.0 °C

time start 9:15 end 9:31 $P_{Bar\,corr}$ None "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.316	.58	73	1746	0			0	0
	f										
2	s		1.316	.58	73	1544	2.3			16.24	2.63
	f										
3	s		1.316	.59	77	1344	4.3			30.36	4.27
	f										
4	s		1.316	.58	77	1144	6.6			46.60	5.58
	f										
5	s		1.316	.58	77	1042	7.1			50.13	5.47
	f										
6	s		1.316	.58	77	944	8.3			58.60	5.79
	f										
7	s		1.310	.58	77	840	9.1			64.25	5.65
	f										
8	s		1.310	.58	78	743	10.1			71.30	5.55
	f										
9	s		1.310	.59	79	642	10.3			72.72	4.89
	f										
10	s		1.310	58	78	546	11.7			82.61	4.72
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Too much load for for motor. Cannot Buck lower than 575 r.p.m. Use Prony Brake for load

Nom. Wind Vel. 4700 fpm
Date 13 May

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 64 °F, P_{Bar} 29.2 "Hg, T_{Bar} ~~25.2~~ 17.0 °C, Time 9:31

COMMENTS:

TTU-NASA WWT TEST DATA

Test No. K-3
Nom. Wind Vel. 500
Date 13 May '82

Performance Test of Model K WWT, Config. Alum. Model by NASA

Test Objective

Test Cond.

Observer(s) M. A. Cadle T_{room} 67 °F; P_{Bar} 29.17 "Hg; T_{Bar} 18.0 °C
time start 2:24 end 2:43 $P_{Bar_{corr}}$ -0.5 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.811	.82	74	2015*	—			?	
	f		1.827	.83	76	2036	—				
2	s		1.811	.82	74	1835**	3.0			19.77	~~3.87~~
	f		1.820	.82	80	1810	2.9				
3	s		1.803	.82	74	1631	5.3			37.42	6.53
	f		1.818	.82	85	1667	5.3				
4	s		1.791	.82	80	1430	7.7			53.66	8.23
	f		1.818	.82	85	1465	7.6				
5	s		1.791	.82	90	1236	9.7			69.20	9.23
	f		1.818	82	85	1275	9.8				
6	s		1.791	.82	80	1037	12.2			84.73	9.56
	f		1.811	82	85	1078	12.0				
7	s		1.791	.82	83	835	14.2			102.38	9.34
	f		1.811	.83	85	871	14.5				
8	s		1.791	.82	83	634	15.9			113.0	7.97
	f		1.811	.82	85	674	16.0				
9	s		1.791	.80	83	438	17.6			125.68	6.18
	f		1.811	.82	88	470	17.8				
10	s									134.16	5.32
	f		1.799	.82	88	379	19.0				
11	s									137.00	3.96
	f		1.799	.82	88	276	18.4				
12	s					176	19.8			139.80	2.58
	f		1.813	.82	88	~~126~~	~~19.2~~				
13	s									77.67	
	f		1.813	.82	86	6	11.0				
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

Rubber coupler slipping after this load

COMMENTS: * Brushes UP - Trans. friction and Pony Brake drag
** Brushes Down - Shaft Coupling friction improved so that a stall was obtained but only at one blade position

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 69 °F, P_{Bar} 29.12 "Hg, T_{Bar} 18.5 °C, Time 2:43

COMMENTS: _____

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Test No. K-4
Nom. Wind Vel. 65 c o
Date 14 May '81

TTU-NASA WWT TEST DATA

Performance Test of Model K WWT, Config. Alum. Model by NASA

Test Objective _____

Test Cond. _____

Observer(s) M. A. Cain T_{room} 67 °F; P_{Bar} 28.93 "Hg; T_{Bar} 20.0 °C
time start 10:50 end 11:25 $P_{Bar_{corr}}$ — : "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.532	1.15	73	2400	—			0	0
	f										
2	s		2528	1.15	73	2252	3.0	6499		21.20	4.99
	f										
3	s		2.519	1.15	80	2056	5.9	6529		41.65	8.96
	f										
4	s		2.512	1.15	80	1057	8.3	6520		58.60	11.40
	f										
5	s					~~1040~~	~~10.6~~	6544		81.20	14.65
	f		2.512	1.15	84	1653	11.5				
6	s		2.499	1.16	84	1453	13.7	6528		96.73	14.07
	f										
7	s		2.499	1.15	84	1251	16.0	6528		112.97	14.79
	f										
8	s		2.492	1.15	85	1046	18.4	6525		129.92	14.23
	f										
9	s		2.484	1.15	85	854	19.8	6514		139.80	12.57
	f										
10	s		2.494	1.15	95	647	21.9	6514		154.63	10.47
	f										
11	s		2.494	1.15	88	453	23.6	6532		166.63	7.90
	f										
12	s		2.484	1.15	88	245	24.7	6532		174.41	4.47
	f										
13	s					~~156~~	~~24.8~~	6532		178.64	2.80
	f		2.484	1.15	88	150	25.3				
14	s					0 ⊛	16.3			115.09	0
	f	18.1 - 16.9 - 14.4 - 15.2 - 12.1 →					Ave.				
15	s	⊛ The following applies to the stall test only.									
	f										
16	s	Bar - 28.96 "Hg.				Tun. temp. - 88°F					
	f	T_{δ} - 19°C				Stat. Pres - 1.18					
17	s	Room - 68°F				Mean - 2.570					
	f	No Load r.p.m - 2434									

COMMENTS: No Load (—) is brushes UP. Transducer & Torque Arm only load. Slippage does not permit checking torque in various blade positions. Stalling occurs only in the minimum pitch

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 69 °F, P_{Bar} 28.91 "Hg, T_{Bar} 20.5 °C, Time 1125

COMMENTS: torque position of blade

Test No. 1-5

TTU-NASA WWT TEST DATA

Nom. Wind Vel. 4000

Date 22 May

Performance Test of Model K WWT, Config. _____

Test Objective Find Stall Torque at various blade positions

Test Cond. _____

Observer(s) M.A. Cook T_{room} 66 °F; P_{Bar} 29.25 "Hg; T_{Bar} 19.5 °C

time start 8:45 end 9:00 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) ~~Arm~~ OZ/in gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		0.473	-.40	80	0	↓			0	0
	f										
2	s		Normal Stall: 5.6 - 5.8				↓				
	f										
3	s		5.4 - 7.4 - 6.4 - 6.4 - 7.1				6.57			46.39	
	f		7.5 = 6.57 Avc →								
4	s		Blade pos. (0): 5.3								
	f		3.7 - 4.1 - 3.0 - 4.3 - 3.7								
5	s		5.1 = 3.98 Avc. →				3.98			28.10	
	f										
6	s		Blade pos 44: 12.1 - 11.8				12.83			90.59	
	f		11.9 - 14.6 - 13.8 - 12.8 →								
7	s		Blade pos. 72: 15.5 - 16.3				15.32			108.17	
	f		14.1 - 16.6 - 15.2 - 14.2 →								
8	s										
	f										
9	s										
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: No Load r.p.m. — 1478 (bearings & torque arm only load)

Nom. Wind Vel. _____ fpm

TTU NASA WWT TEST DATA (continued)

Date _____

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} ~~Hung~~ ~~73~~ 66 °F, P_{Bar} ~~29.26~~ 29.25 ~~Hg~~ "H_2O, T_{Bar} ~~18.6~~ 19.5 °C, Time ~~9:33~~ 9:00

COMMENTS: _____

Test No. K-6

TTU-NASA WWT TEST DATA

Nom. Wind Vel. 6500

Date 22 May

Performance Test of Model K-3 WWT, Config.

Test Objective To determine if stall conditions change Speed/Power

Test Cond. radio Curve. Refer to K-3 test

Observer(s) D. A. Elliott T_{room} 67 °F; P_{Bar} 29.65 "Hg; T_{Bar} 19.5 °C

time start 9:15 end 9:48 $P_{Bar_{corr}}$ [illegible] "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.587	1.18	83	2430	No Load			0	0
	f										
2	s		2.587	1.18	83	2281	2.9			20.47	4.89
	f										
3	s		2.563	1.18	83	2081	6.3			44.48	9.69
	f										
4	s		2.580	1.18	85	1880	8.5			60.02	11.81
	f										
5	s		2.580	1.18	87	1680	11.3			79.79	14.03
	f										
6	s		2.588	1.18	87	1480	13.7			96.73	14.99
	f										
7	s		2.562	1.18	87	1280	17.1			120.7	16.17
	f										
8	s		2.553	1.18	87	1083	19.3			136.3	15.45
	f										
9	s		2.553	1.18	90	885	21.8			153.9	14.26
	f										
10	s		2.553	1.18	90	680	23.1			163.1	11.61
	f										
11	s		2.553	1.18	90	484	24.6			173.7	8.80
	f										
12	s		2.553	1.18	92	283	25.6			180.7	5.35
	f										
13	s		2.553	1.18	92	180	26.8			189.2	3.56
	f					~~144~~	>				
14	s		2.553	1.18	92	119	26.5			187.1	2.33
	f										
15	s		2.553	1.18	92	107	27.5			194.2	2.17
	f										
16	s	some slipping				0					
	f										
17	s										
	f										

COMMENTS: It is possible the normal stall was not obtained (vs K-3 test) due to the higher temperature in tunnel

This test taped all coupling joints in addition to having the

(C. TTU-NASA WWT TEST DA(C- Test No. K-7
Nom. Wind Vel. 7000 ft
Date 22 May'8

Performance Test of Model K-3 WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) M.G. Cesare T_{room} 70 °F; P_{Bar} 29.25 "Hg; T_{Bar} 21.0 °C
time start 11:45 end 12:05 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Axem) oz/in gm	Velocity V_w fpm	m/s	Torque T mN·m	Power P Watts
1	s		2.946	.38	78	2582	No Load				
	f										
2	s		2.946	.38	78	2450	3.0			21.18	5.43
	f										
3	s		2.946	.38	85	2246	6.5			45.89	10.79
	f										
4	s		2.936	.38	85	2043	9.8			69.20	14.80
	f										
5	s		2.936	.38	87	1832	12.5			88.26	16.92
	f										
6	s		2.936	.38	87	1644	15.1			106.6	18.35
	f										
7	s		2.922	.38	87	1448	18.2			128.5	19.48
	f										
8	s		2.922	.38	87	1243	20.6			145.5	18.93
	f										
9	s					2605	No Load				
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: *Survey Test Not intended to be Complete

TTU-NASA WWT TEST DATA

Test No. K-5
Nom. Wind Vel. 5500 fpm
Date 19 June 81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Wing ports open. Front port and top of wheel blocked

Observer(s) M. A. Geer T_{room} 93 °F; P_{Bar} 29.17 "Hg; T_{Bar} 28.0 °C

time start 1:30 end 1:55 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.817	.87	87	1528	No load			[illegible]	0
	f										
2	s		1.817	.87	92	1232	2.9			20.47	2.64
	f										
3	s		1.817	.87	92	1033	4.9			35.60	3.85
	f										
4	s		1.817	.87	92	835	7.1			50.13	4.38
	f										
5	s		1.817	.87	94	634	7.9			55.78	3.70
	f										
6	s		1.817	.87	94	434	9.7			68.50	3.11
	f										
7	s		1.817	.87	94	339	9.1			64.25	2.28
	f										
8	s		1.817	.87	94	239	11.3			79.80	2.00
	f										
9	s		1.817	.85	95	~~136~~ 139	~~11.3~~ 10.5			74.14	1.08
	f										
10	s		1.798	.85	95	77	9.8			69.20	0.56
	f										
11	s		1.798	.85	95	0	5.9			41.66	0
	f										
12	s		1.798	.85	95	1527	No load				
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Only one stall point possible - slippage occuring at intermediate points. "No load" is transducer with brushes raised plus torque arm

Test No. K-3 pg 2

Nom. Wind V. 5500 fpm

Date 19 Mar '91

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} 83 °F, P_{Bar} 29.16 "H_2O, T_{Bar} 20.6 °C, Time 1:55

COMMENTS: _____

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TTU-NASA WWT TEST DATA

Test No. K-9
Nom. Wind Vel. 6500 fpm
Date 19 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-9

Test Cond. Same as K-9 (except wind vel.)

Observer(s) Jim G. Coker T_{room} 84 °F; P_{Bar} 29.16 "Hg; T_{Bar} 25.0 °C

time start 2:50 end 3:13 $P_{Bar_{corr}}$ _____ "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Stat. Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.604	1.25	93	1859	No load			0	0
	f										
2	s		2.570	1.25	93	1607	3.3			23.30	3.92
	f										
3	s		2.565	1.25	95	1407	5.1			36.00	5.30
	f										
4	s		2.565	1.25	95	1202	7.2			50.84	6.35
	f										
5	s		2.565	1.25	98	1005	9.2			65.00	6.84
	f										
6	s		2.565	1.25	98	908	10.3			72.72	6.91
	f										
7	s		2.565	1.25	98	802	11.4			80.50	6.76
	f										
8	s		2.565	1.25	100	708	12.3			86.85	6.44
	f										
9	s		2.565	1.23	100	607	13.6			91.80	5.83
	f										
10	s		2.565	1.23	100	507	13.7			96.73	5.13
	f										
11	s		2.565	1.23	100	408	13.5			95.32	4.07
	f										
12	s		2.565	1.23	100	304	14.4			101.70	3.29
	f										
13	s		2.560	1.20	102	208	15.0			105.90	2.31
	f										
14	s		2.529	1.20	102	109	14.1			99.56	1.14
	f										
15	s		2.529	120	104	0	8.7			61.43	0
	f										
16	s		2.529	1.20	104	1842	No Load				
	f										
17	s										
	f										

COMMENTS. Only one stall point possible - slippage occuring at intermediate points. "No Load" is transducer with brushes raised + torque arm

Test No. _____ pg

Nom[illegible] Ind Vel. _____ fpm

Date _____

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85 °F, P_{Bar} 29.16 "H_2O, T_{Bar} 28.0 °C, Time 3:13

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-10
Nom. Wind Vel. 5500 fpm
Date 22 June 81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Wheel Open - Front Port and Wings Blocked

Observer(s) M. A. Coffee T_{room} 83 °F; P_{Bar} 29.12 "Hg; T_{Bar} 28.5 °C

time start 10:50 end 11:15 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.822	.85	84	1542	No Load			0	0
	f										
2	s		1.822	.85	87	1266	3.1			21.89	2.90
	f										
3	s		1.789	.85	81	1054	4.8			33.90	3.74
	f										
4	s		1.788	.85	90	965	6.7			47.30	4.28
	f										
5	s		1.809	.85	90	668	7.6			53.66	3.75
	f										
6	s		1.769	.85	92	565	7.6			53.66	3.17
	f										
7	s		1.780	.84	92	460	8.2			57.90	2.79
	f										
8	s		1.773	.84	92	361	7.9			55.78	2.11
	f										
9	s		1.774	.84	94	261	8.4			59.31	1.62
	f										
10	s		1.774	.84	94	166	9.3			65.67	1.14
	f										
11	s		1.802	.84	94	103	9.1			64.25	0.69
	f										
12	s		1.802	.84	94	0	6.4			45.20	0
	f										
13	s		1.902	.84	95	1543	No Load				
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Only one stall point possible - Slippage occuring at intermediate points. "No Load" is transducer with brushes raised plus torque arm.

Test No. A-10 pg
Nom Wind Vel. 5500 fpm
Date 26 June '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} 84 °F, P_{Bar} 29.12 "H_2O, T_{Bar} 28.5 °C, Time _____

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-11

Nom. Wind Vel. 6500 fpm

Date 22 June 81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-10

Test Cond. Same as K-10 (except wind vel.)

Observer(s) M. A. Collins T_{room} 84 °F; P_{Bar} 29.13 "Hg; T_{Bar} 28.5 °C

time start 12:05 end 12:25 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.603	1.23	87	1890	No Load			0	0
	f										
2	s		2.603	1.23	88	1664	3.0			21.18	3.69
	f										
3	s		2.603	1.23	95	1462	5.2			36.71	5.54
	f										
4	s		2.603	1.23	95	1261	7.3			51.54	6.80
	f										
5	s		2.603	1.23	95	1063	9.8			69.20	7.70
	f										
6	s		2.551	1.23	98	968	10.3			72.73	7.37
	f										
7	s		2.556	1.23	98	864	10.8			76.26	6.90
	f										
8	s		2.556	1.23	98	769	11.1			78.38	6.31
	f										
9	s		2.556	1.23	100	664	11.1			78.38	5.45
	f										
10	s		2.556	1.23	100	566	10.9			76.96	4.56
	f										
11	s		2.556	1.23	100	464	10.8			76.26	3.70
	f										
12	s		2.556	1.23	100	366	11.7			82.61	3.16
	f										
13	s		2.556	1.23	100	262	12.7			89.67	2.46
	f										
14	s		2.556	1.23	103	169	13.8			97.44	1.72
	f										
15	s		2.538	1.23	103	102	13.2			93.20	0.99
	f										
16	s		2.539	1.23	103	6	10.8			76.26	0
	f										
17	s		2.538	1.23	103	1888	No Load				
	f										

COMMENTS: _____

Test No. R-11

No. , Wind Vel. 6500 fpm

Date 22 Mar '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
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25	s										
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26	s										
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27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85 °F, P_{Bar} 29.13 "H_2O, T_{Bar} 26.5 °C, Time 12:25

COMMENTS: _____

TTU-NASA WWT TEST DATA

Nom. Wind Vel. 5500 fpm

Date 22 June '91

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Front port and wheel open - wings blocked

Observer(s) _____ T_{room} 85 °F; P_{Bar} 29.12 "Hg; T_{Bar} 29.0 °C

time start 1:32 end 2:02 $P_{Bar_{corr}}$ _____ "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.780	.83	95	1496	No Load			0	0
	f										
2	s		1.780	.83	95	1122	3.5			24.71	2.90
	f										
3	s		1.780	.83	97	918	4.4			31.07	2.98
	f										
4	s		1.780	.83	97	720	5.4			38.13	2.87
	f										
5	s		1.780	.83	97	626	6.3			44.50	2.92
	f										
6	s		1.780	.83	98	520	6.5			45.90	2.50
	f										
7	s		1.780	.83	98	422	8.5			60.02	2.65
	f										
8	s		1.780	.83	98	322	8.3			56.60	1.91
	f										
9	s		1.780	.83	98	220	9.3			65.66	1.51
	f										
10	s		1.780	.83	100	124	10.2			72.02	0.93
	f										
11	s		1.780	.83	100	75	11.2			79.10	0.62
	f										
12	s		1.780	.83	100	0	9.4			66.37	0
	f										
13	s		1.780	.83	100	1496	No Load				
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Test No. A-12

Nom Ind Vel. 5500 fpm

Date 22 June '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 96 °F, P_{Bar} 29.12 "H_2O, T_{Bar} 29.0 °C, Time 2:02

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-13
Nom. Wind Vel. 6500 fpm
Date 22 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-12

Test Cond. Same as K-12 (except wind vel.)

Observer(s) _____ T_{room} 81 °F; P_{Bar} 29.12 "Hg; T_{Bar} 29.0 °C

time start 2:40 end 3:05 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz"/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.554	1.20	98	1832	No Load			0	0
	f										
2	s		2.528	1.20	100	1568	3.2			22.59	3.71
	f										
3	s		2.545	1.20	100	1358	4.6			32.48	4.62
	f										
4	s		2.543	1.20	101	1162	5.9			41.66	5.07
	f										
5	s		2.532	1.20	102	962	7.0			49.43	4.98
	f										
6	s		2.532	1.20	102	868	7.6			53.66	4.87
	f										
7	s		2.532	1.20	102	763	8.3			58.60	4.68
	f										
8	s		2.523	1.20	102	656	9.7			68.50	4.70
	f										
9	s		2.523	1.20	103	561	9.7			68.50	4.02
	f										
10	s		2.523	1.20	103	465	11.5			82.61	4.02
	f										
11	s		2.510	1.20	103	362	11.9			84.02	3.18
	f										
12	s		2.510	1.20	105	262	12.8			90.38	2.48
	f										
13	s		2.510	1.20	105	161	14.3			100.1	1.69
	f										
14	s		2.510	1.20	105	100	15.5			109.4	1.14
	f										
15	*s		2.510	1.20	105	0	9.4			66.37	0
	f										
16	s		2.510	1.20	105	1824	No Load				
	f										
17	s										
	f										

COMMENTS: *It has been noted the stall torque shifts from a higher average to a lower one, e.g. Pt. 15 – 10.4 to 9.4. Is this part of the slippage problem? (over)

TTU NASA WWT TEST DATA (continued)

Test No. _____
Nom. Wind Vel. _____ fpm
Date _____

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} 87 °F, P_{Bar} 29.10 "H_2O, T_{Bar} 29.5 °C, Time 3.05

COMMENTS: Why should this stall torque be the same as K-12, when the the overall torque of K-13 is greater than K-12

TTU-NASA WWT TEST DATA

Test No. K-14
Nom. Wind Vel. 55-00 fpm
Date 23 June '91

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Front Port open - wheel and wings blocked

Observer(s) M. A. Cruz T_{room} 82 °F; P_{Bar} 29.28 "Hg; T_{Bar} 27.5 °C

time start 9:05 end 9:24 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.802	.82	87	962	No Load			0	0
	f										
2	s		1.802	.82	87	528	3.7			26.12	1.44
	f										
3	s		1.802	.82	87	425	4.2			29.65	1.32
	f										
4	s		1.802	.82	89	329	4.7			33.18	1.14
	f										
5	s		1.802	.82	89	223	5.8			40.95	0.95
	f										
6	s		1.802	.82	89	128	6.2			43.78	0.58
	f										
7	s		1.862	.82	89	81	6.7			47.31	0.40
	f										
8	s		1.862	.82	90	0	4.1			28.95	0
	f										
9	s		1.862	.82	90	964	No Load				
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Test No. K-14 pg.

Non Wind Vel. 5500 fpm

Date 23 June '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} 82 °F, P_{Bar} 29.28 "H_2O, T_{Bar} 27.5 °C, Time 9:24

COMMENTS:

TTU-NASA WWT TEST DATA

Test No. K-15
Nom. Wind Vel. 6.5AA
Date 23 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-14

Test Cond. Same as K-14 (except wind vel.)

Observer(s) M. A. Cortez T_{room} 88 °F; P_{Bar} 29.69 "Hg; T_{Bar} 27.5 °C

time start 9:30 end 9:51 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.587	1.18	92	1184	No Load			0	0
	f										
2	s		2.597	1.18	92	816	3.4			24.00	2.05
	f										
3	s		2.567	1.18	92	716	4.5			31.80	2.39
	f										
4	s		2.561	1.18	95	617	5.4			38.13	2.46
	f										
5	s		2.567	1.18	95	515	5.6			39.54	2.13
	f										
6	s		2.567	1.18	95	417	7.3			51.54	2.25
	f										
7	s		2.567	1.18	95	312	8.0			56.49	1.84
	f										
8	s		2.567	1.18	97	214	8.3			58.60	1.31
	f										
9	s		2.567	1.18	97	114	9.7			68.49	0.82
	f										
10	s		2.567	1.18	97	85	9.1			64.25	0.57
	f										
11	s		2.567	1.18	97	0	8.7			61.43	0
	f										
12	s		2.545 ?	1.18	100	1190	No Load				
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Test No. A-1.5" pg
Nom. C .d Vel. 6500 fpm
Date 23 June '81

TTU NASA WT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 83 °F, P_{Bar} 29.20 "Hg, T_{Bar} 27.5 °C, Time 9:51

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-16
Nom. Wind Vel. 5500
Date 23 June '87

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine Performance with Selected Ports Blocked

Test Cond. Front Duct and Wings Open - Wheel blocked

Observer(s) M. A. Cocuk T_{room} 84 °F; P_{Bar} 27.30 "Hg; T_{Bar} 28.0 °C

time start 10:40 end 11:05 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.816	.84	92	1822	No Load			0	0
	f										
2	s		1.813	.84	92	1615	3.4			24.00	4.06
	f										
3	s		1.813	.84	93	1417	5.9			41.65	6.18
	f										
4	s		1.813	.84	93	1217	8.2			57.90	7.38
	f										
5	s		1.813	.84	96	1017	10.9			76.26	7.73
	f										
6	s		1.786	.84	96	819	13.1			92.50	7.93
	f										
7	s		1.806	.84	96	716	13.6			96.02	7.20
	f										
8	s		1.806	.84	98	614	14.0			98.85	6.35
	f										
9	s		1.806	.84	98	514	15.2			107.3	5.77
	f										
10	s		1.796	.84	98	417	14.4			101.7	4.44
	f										
11	s		1.796	.84	100	316	15.7			110.9	3.66
	f										
12	s		1.796	.84	100	216	16.6			117.2	2.65
	f										
13	s		1.796	.84	100	114	17.2			121.4	1.45
	f										
14	s		1.796	.84	100	0	11.5			81.2	0
	f										
15	s		1.796	.84	101	1820	No Load				
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Test No. 1-16 pg 2

Nom. VC 1 Vel. 5500 fpm

TTU NASA WWT TEST DATA (continued)

Date 23 June '91

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85 °F, P_{Bar} 29.3 "Hg, T_{Bar} 29.0 °C, Time 11:09

COMMENTS: _____

_____

ORIGINAL PAGE IS
OF POOR QUALITY

TTU-NASA WWT TEST DATA

Test No. K-17
Nom. Wind Vel. 6500
Date 23 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-16

Test Cond. Same as K-16 (except wind vel.)

Observer(s) M. A. Cairns T_{room} 95 °F; F_{Bar} 29.30 "Hg; T_{Bar} 28.0 °C
time start 11:40 end 12:13 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.552	1.20	92	2183	No Load			0	0
	f										
2	s		2.548	1.20	97	2020	3.2			22.59	4.78
	f										
3	s		2.548	1.20	97	1818	6.6			46.60	8.87
	f										
4	s		2.514	1.20	100	1620	9.3			65.66	11.14
	f										
5	s		2.523	1.20	100	1419	11.5			81.20	12.06
	f										
6	s		2.523	1.18	102	1222	14.3			100.8	12.90
	f										
7	s		2.523	1.18	102	1019	16.9			119.3	12.73
	f										
8	s		2.523	1.18	102	922	18.5			130.6	12.61
	f										
9	s		2.523	1.18	105	820	19.5			137.7	11.82
	f										
10	s		2.523	1.18	105	722	19.3			136.3	10.30
	f										
11	s		2.523	1.19	105	621	20.3			143.3	9.32
	f										
12	s		2.523	1.18	105	515	20.6			145.5	7.84
	f										
13	s		2.518	1.18	105	416	22.0			155.3	6.76
	f										
14	s		2.519	1.18	107	315	22.4			158.2	5.22
	f										
15	s		2.519	1.18	107	216	22.7			160.3	3.62
	f										
16	s		2.519	1.18	107	186	22.9			161.7	3.15
	f										
17	s		2.519	1.18	107	0	12.2			86.1	0
	f										

COMMENTS: over for No Load

Nom. V, Vel. 6500 fpm

Date 23 Aug '87

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s		2.519	1.2	107	2176	No Load				
	f			1.18							
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85.5 °F, P_{Bar} ~~29.90~~ 29.28 "Hg, T_{Bar} 29.5 °C, Time 12:13

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-19
Nom. Wind Vel. 55.00
Date 23 June '82

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine Performance with selected ports blocked

Test Cond. Front Port Blocked - Wings and Wheel open

Observer(s) M. A. Cochil T_{room} 85 °F; P_{Bar} 29.27 "Hg; T_{Bar} 28.5 °C

time start 1:35 end 2:08 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.791	.87	93	2082	No Load			0	0
	f										
2	s		1.791	.87	93	1889	3.5			24.71	4.89
	f										
3	s		~~1.791~~	.87	93	1685	6.1			43.07	7.60
	f		1.787								
4	s		1.787	.87	96	1482	8.1			57.20	8.87
	f										
5	s		1.787	.87	96	1285	10.3			72.73	9.78
	f										
6	s		1.787	.87	96	1091	12.4			87.55	10.00
	f										
7	s		1.787	.87	96	997	13.5			95.32	9.95
	f										
8	s		1.787	.87	98	890	14.9			105.2	9.90
	f										
9	s		1.761	.85	98	782	16.5			116.5	9.54
	f										
10	s		1.761	.85	98	684	17.3			122.1	8.74
	f										
11	s		1.761	.85	98	584	17.7			125.0	7.64
	f										
12	s		1.761	.85	100	483	17.2			121.4	6.14
	f										
13	s		1.761	.85	100	383	16.5			116.5	4.67
	f										
14	s		1.761	.85	100	284	18.2			128.5	3.82
	f										
15	s		1.761	.85	100	188	19.0			134.1	2.64
	f										
16	s		1.761	.85	102	0	10.6			74.8	0
	f										
17	s		1.761	.85	102	2078	No Load				
	f										

COMMENTS: _____

Nom. VC Vel. 5500 fpm

TTU NASA WWT TEST DATA (continued)

Date 23 June '87

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85.5 °F, P_{Bar} 29.27 "Hg, T_{Bar} 28.5 °C, Time 2108

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-19
Nom. Wind Vel. 65-00
Date 24 June '81

Performance Test of Model ____ WWT, Config. _____

Test Objective Same as K-18

Test Cond. Same as K-18 (except wind vel.)

Observer(s) W. A. Couch T_{room} 83 °F; P_{Bar} 29.32 "Hg; T_{Bar} 28.0 °C
time start 8:55 end 9:15 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.594	1.25	85	2475	100 Lock			0	0
	f										
2	s		2.594	1.25	87	2307	3.3			23.30	5.63
	f										
3	s		2.594	1.25	87	2102	6.5			45.90	10.10
	f										
4	s		2.586	1.25	89	1902	9.2			64.96	12.94
	f										
5	s		2.586	1.25	92	1705	11.8			83.32	14.87
	f										
6	s		2.577	1.25	92	1505	15.1			106.6	16.80
	f										
7	s		2.577	1.25	92	1300	17.6			124.3	16.92
	f										
8	s		2.563	1.25	95	1112	19.9			140.5	16.36
	f										
9	s		2.552	1.25	95	909	23.3			164.5	15.65
	f										
10	s		2.552	1.25	95	703	25.2			177.9	13.09
	f										
11	s		2.552	1.25	97	597	25.0			176.5	11.03
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Slippage at shaft outside tunnel

Final: P_B = 29.32 T_B = 28.0°C Time 9:15

APPENDIX B
CALCULATIONS

1. Wind Velocity - from wind tunnel measurements

$$V_w = \frac{2 P_v}{\rho_w}$$

P_v, velocity pressure in psf units

$P_v = P_v'$ ("H_2O) $5.2 \frac{psf}{"H_2O}$

P_s = static pressure

$$P_w = \frac{P}{RT}_{Tunnel} = \frac{P_{Bar}("Hg)70.75 + P_s("H_2O)5.2 \frac{Psf}{"H_2O}}{53.35\ T_w(°F) + 460}$$

T_w = wind tunnel temperature in °F

R = specific gas constant = $53.35 \frac{ft\ lbf}{lbm\ °R}$ for air

$$V_w = \left\langle \frac{2(5.2)P_v'\ (T_w + 460)\ g_c}{1.326\ P_{Bar} + 0.0975\ P_s} \right\rangle^{1/2} \frac{ft}{sec}$$

2. Blade Velocity - of WWT rotor

$$V_B = V_{Blade\ Tip} = \omega R = 2\pi \left\langle \frac{N(rpm)}{60} \right\rangle R(ft)$$

3. Wind Power - in wind tunnel

$$P_w = \rho_w A_c V_w \left(\frac{V_w^2}{2}\right)$$

ρ_w = density = $\frac{P}{RT}$ as above

A_c = wind collector area in ft^2

V_w = wind velocity in ft/sec

$P_w = 0.042\ \rho A_c V^3$ watts

4. Shaft Power - measured by torque transducer

$P_{sh} = cTN =$

T = measured torque in milli-Newton meters (mNm)

N = measured shaft speed in Rev/min

C = conversion factor

$P_{sh} = 0.1047T\left(\frac{N}{1000}\right)$ watts

5. Power Coefficient

$$C_p = \frac{P_{sh}}{P_w} = \frac{0.1047T\left\langle \frac{N}{1000} \right\rangle}{0.042\rho A_c V^3}$$ dimensionless

6. Speed Ratio

$$\frac{V_{Rotor}}{V_w} = \frac{V_B}{V_w} = \frac{\frac{2\pi \frac{N}{60}}{10.4P_v'(T_w + 460)g_c}}{1.326P_{Bar} + 0.0975P_s}$$ dimensionless

FINAL REPORT

on

EVALUATION OF A WIND TURBINE ELECTRIC POWER GENERATOR

for

National Aeronautics and Space Administration
Marshall Space Flight Center

on

NASA NAG-8007 Research Grant

for

Grant Period

June 1, 1980 to September 15, 1981

by

William B. Swim
Project Director

Department of Mechanical Engineering
Tennessee Technological University
Cookeville, TN 38501

October 15, 1981

Final Report to
NASA Marshall Space Flight Center

on

EVALUATION OF A WIND TURBINE ELECTRIC POWER GENERATOR

NASA NAG-8007

William B. Swim, Project Director
Tennessee Technological University

October 15, 1981
Cookeville, TN 38501

INTRODUCTION

The results of experimental work under NASA NAG-8007 and Supplement 1 to that Research Grant are reported herein. The work, wind tunnel evaluation of NASA's Wind Wheel Turbine (WWT) was initiated in June 1980 and completed in August 1981. The technical monitor on the project was, the WWT inventor, Mr. John W. Kaufman, Fluid Dynamics Branch, Atmospheric Sciences Division.

Objectives

The three objectives of the project were to:

1. Provide a technical assessment of the aerodynamic performance of the WWT.

2. Evaluate the potential of the wind wheel turbine in utilizing wind as an alternate power source and

3. Develop scaling parameters to predict the aerodynamic performance of WWT prototype sized to produce 3, 9, 30 and 100 kw outputs in a 6.7 m/sec (15 miles per hour) wind.

Scope

The following tasks were completed under this Grant:

A. Construct a scale model, Model A, of the WWT from description supplied by NASA.

B. Design and set up a performance measuring system for the WWT in the Tennessee Technological University (TTU) wind tunnel.

C. Measure the performance, rotor speed and torque, of Model A WWT at steady wind tunnel speeds of 28, 33 and 38 meters/sec (62.5, 73.8 and 85.2 mph).

D. Design, set up and run a spin-up, spin-down test system for the WWT, Model A.

E. Instrument and measure the performance of Model K WWT, supplied by NASA, at steady wind tunnel speeds of 28, 33 and 38 meters/sec.

F. Measure the performance of the individual wind inlets, singularly and in pairs, for the Model K WWT.

G. Analyze the performance data and compare to data on other types of wind turbines.

H. Extrapolate the performance of the models to homologous prototype with shaft outputs of 3, 9, 30 and 100 kw.

EXPERIMENTAL SYSTEMS

Wind Tunnel Tests

Steady state performance of the WWT models were run in the Tennessee Technological University Wind Tunnel, a low velocity recirculation tunnel with a test section 2 ft high x 3 ft wide x 10 ft long. The turbine models were mounted on the center line of the test section and connected to an external torquemeter and revolution counter by a shaft extending through the side of the test section. Torque measurements were made with a Lebow strain gage type torquemeter and digital indicator/amplifier. The torque sensor contained a 60 tooth gear and magnetic pickup. The gear and pickup system provided a pulse signal to an electronic counter/timer which would display the rotor speed. Wind tunnel velocity was measured by a pitot tube connected to a micromanometer. The wind tunnel test system is illustrated in Figure 1.

Spin Up - Spin Down Test System

Transient data on WWT, Model A, was obtained using an open, blow through wind tunnel illustrated in Figure 2. The model was mounted at the exit of the tunnel. Wind velocity was determined by an upstream pitot probe and inclined manometer which was calibrated against a velocity probe located at the position

where the model would be placed. The rotor speed of the model was measured by a magnetic pickup and 60 tooth gear, set out of the wind stream and connected to the rotor by a light aluminum shaft. Timed count rates during spin up and spin down provided data on rotor acceleration.

Spin-up tests were run by placing the WWT model, with rotor locked, in the air stream with the desired wind speed. The rotor was released and the revolutions as a function of time were recorded. When the steady state speed was reached, this maximum shaft speed was also recorded.

Spin-down tests were run starting from the steady state conditions of the spin-up tests. A damper in the wind tunnel was closed to divert the flow out the side of the tunnel. Speed-time data was recorded as the rotor coasted to a stop. These tests were run at model inlet air velocities of 10.4, 11.7, 13.2 and 16.5 meters/sec (2050, 2300, 2600 and 3250 ft/min).

Model A, WWT

A scale model WWT, designated the Model A, was built of plexiglass following the descriptive sketches supplied by NASA. The dimensions of the Model A, with a rotor diameter of 14 cm (5.51 in.), are given in Figure 3, 4 and 5. A photograph of the completed unit is shown in Figure 6.

The Model A WWT had wheel dimensions and measured wind collector areas as shown below:

Wheel: dxw & projected area	5 1/2" x 1 7/8"	10.31 sq in	or	66.5	sq cm
Front collector	3 1/4" x 2 13/16"	9.14 sq in	or	59.0	sq cm
Top projection of rotor	1 7/8" x 2 3/4"	5.16 sq in		33.3	sq cm
Side collectors	∿ 2 13/16" x 3" ea	16.74 sq in		108.0	sq cm
Bottom deflector	2 3/4" x 3/4"	2.06 sq in		13.3	sq cm
Total Collector Area		33.13 sq in		213.7	sq cm

Model K, WWT

The Model K WWT, an aluminum model built and supplied by NASA, was about 40% larger than the Model A. It is illustrated by sketches in Figure 7, 8 and 9 and by

photograph in Figure 10. The major dimensions are shown in the sketches as scaling units.

The measured wheel dimensions and wind collector areas for the Model K WWT are:

Wheel: dxw & projected area	8 3/16" x 2 3/4"	= 22.52 sq in	or 145.26 cm^2
Front collector	~ 3 17/18" x 3 1/2"	13.85 sq in^2	89.35 cm^2
Top projection of rotor	2 3/4" x 4 9/16"	12.55 sq in^2	80.97 cm^2
Side collectors	~ 4 1/8" x 3 15/16"	31.96 sq in	206.19 cm^2
Bottom deflector	3 13/16" x 1 1/4"	4.76 sq in	30.71 cm^2
Total Collector Area		63.12 sq in	407.22 cm^2

RESULTS

Performance Tests

Power and torque test data, runs A-1 to A-11 for the Model A WWT and K-1 to K-7 for the Model K WWT are attached in the Appendix A. The methods of data reduction, to obtain torque shaft power and wind energy, are shown in Appendix B.

Representative performance curves for Model A, torque and power plotted against shaft speed for wind velocities of 28, 33 and 36 m/sec (5500, 6500 and 7000 ft/min) are plotted as Figures 11, 12 and 13.

Performance curves for the Model K WWT, at wind velocities of 20 to 36 m/sec (4700 to 7000 ft/min) are given in Figures 14, 15 and 16.

Nondimensional performance measures, torque coefficient C_T, and power coefficient C_p, are plotted vs the velocity ratio in Figure 17.

Spin Up and Spin Down Tests

Data for the spin-up and spin-down tests, run using the Model A WWT, are given in Appendix C. The results of the spin tests are plotted in Figures 18 and 19. Also shown on these plots are the earlier Kaufman spin test data[1], taken using an earlier stainless steel WWT model.

---

[1]Advanced and Innovative Wind Wheel Turbine, M.S. Thesis of John W. Kaufman, University of Tennessee, December 1979.

Discussion

The performance data from Models A and K are similar. Figures 11, 12 and 13 for the Model A and Figures 14, 15 and 16 for the Model K show that both have almost a linear decreasing shaft torque with increasing shaft speed. The maximum rotor speed, at zero shaft torque, occurs when bearing friction and rotor windage losses balance the wind energy extracted by the rotor.

An instability in the Model A torque curve, a local flatening of the torque with speed, generally occurs at least once in each performance curve. The flat spots in the torque curve can cause a relative peak in power output. This instability or hysteres s does not appear to be an experimental fluke. All the tests of the Model A exhibited this instability phenomena at about 65% of max speed. A second instability occurs at about 20% of max rotor speed. A third instability occurs when the rotor is locked. The locked-rotor torque is strongly dependent on the position of the rotor blades with respect to the housing flow paths. A 2 to 1 swing in stall torque occurred as the position of the locked rotor varied over a 45° interval, a blade passage interval.

The Model K performance curves were smoother than the Model A and did not exhibit the same type of flat spots. However the K model had the same variation of stall torque, with the torque varying strongly with the static blade position.

The normalized performance curves, Figure 17, compare the Models A and K for the several tests. The better performance of the larger Model K was expected based on size considerations. But the magnitude of improvement was larger than anticipated. Using a Reynolds Number analogy to deduce the influence of size on turbine performance,

$$\frac{1 - \eta_1}{1 - \eta_2} = \left(\frac{D_2}{D_1} \right)^{0.2}$$

would indicate the losses in the smaller turbine would exceed the larger units loss by 7%. Measured decreases in C_p, the power coefficient between the Model K and the Model A were found to be around 42%

The significance of the spin data is rather obscure. The validity of comparing the current Model A data to earlier NASA data appears nil. The spin data is a measure of the inertia of the rotor, the frictional losses in the turbine rotor and lastly the efficiency of the turbine in converting wind energy into mechanical energy. The performance assessment of the WWT can best be done by eliminating the confusing influences of inertia and rotor frictional losses. This was done in the steady state performance measurements discussed above. The direct measure of performance is much superior to the indirect spin test methods.

Performance of Individual Wind Collection System

The Model K WWT was run with only one or two of the three air collection systems being open to the wind. One or more inlets--front, side ports or top--were covered to prevent wind from entering the wheel via that passage. The measured performance of the turbine was normalized by dividing by a wind energy factor scaled to the collector area actually open to the wind. This procedure allows the effectiveness of each collector & duct system to be evaluated individually. Comparing the decrease in normalized performance of two systems operating together from the performance of the individual systems gives a measure of the interference of one system with another.

It is clear that the top port is the most efficient air collection system, based on peak power coefficient. The front port is next and the side wings have the lowest peak power coefficient, all based on the actual wind collection area open.

Combining the operating of the front and wheel side collectors reduces the power coefficient to the lower of the two. The two collectors together are little better than the front port alone. The performance of the complete wind turbine, the heavy solid line on the C_p & C_T plots, show that the performance comes up slightly when adding the side collectors to the front and the wheel wind inlets. But the performance of the other two collector configurations, wheel top and sides or

front and sides, is reduced by adding the third collector. Combinations including the front and the wheel top have reduced performance. The air flows from the front and the wheel top are shown to have strong negative interactive effects.

These results show that strong interactions--the flow from one collector bucking or flowing counter to a second stream--can cause a sharp degregation of performance. The collectors and wheel are not designed to work harmoniously together.

One of the primary WWT design problems is the paddle wheel, an inefficient low speed design. The flow entering a bucket to generate a rotor torque must turn around at the bottom of the blade passage and flow out counter to the in-flow stream. This is an inefficient design. The flow leaving a blade passage may, due to wheel rotation, find itself flowing counter to a fresh air stream from another collector system. This second counter current stream again takes its toll, reducing turbine output and lowering the efficiency.

The paddle wheel blade design, inherently counter flow in operation, needs to be replaced with a pure radial in-flow rotor. The wind would be introduced to aerodynamically shaped blades on the periphery of the rotor. The air passes through the blade passages, producing a rotor torque. The air would continue its radial inflow and be discharged through one or two axial openings at the center of the rotor.

Scaling

The performance of the WWT models can be scaled-up using turbomachinery similarity rules or "fan laws" and a model of the behavior of flow losses with unit size. The similarity rules for incompressible flow are

$$\text{Flow:} \quad Q \propto ND^3$$

$$\text{Head:} \quad H \propto N^2D^2$$

$$\text{Power:} \quad P \propto N^3D^5$$

A well accepted turbine loss model, the Moody model, is given on page 5. This

C-2

flow model can be used to determine the viscous flow losses and performance of WWT prototypes from the measured wind tunnel performance of the WWT models. The Moody loss model is:

$$\frac{1 - \eta_1}{1 - \eta_2} = \frac{(\text{flow losses})_1}{(\text{flow losses})_2} = \left(\frac{D_2}{D_1} \right)^{0.2}$$

This model can also be based on Reynolds number, $N_{Re} = \frac{DV}{\nu}$ rather than just size. For model tests in air, the speed ratio between model and prototype and the diameter ratio influence the flow losses such that

$$\frac{(1 - \eta_1)}{(1 - \eta_2)} = \frac{(\text{flow losses})_1}{(\text{flow losses})_2} = \left(\frac{N_{Re_2}}{N_{Re_1}} \right)^{0.2}$$

Adapting these relationships to the wind turbine scaling problem yields:

$$\text{Wind power} = P_w \propto V_w^3 D^2$$

$$\text{Power coefficient} = C_p = \frac{P_{shaft}}{P_{wind}}$$

$$\text{Shaft power} = P_{sh} \propto C_p V_w^3 D^2$$

The Model K data needed in scaling is:

$$C_{p_{Peak_M}} = 0.019$$

$$\text{at } V_{w_M} = 33 \text{ m/sec and}$$

$$D_{w_M} = 0.208 \text{ m with}$$

$$\text{Acollector}_M = 0.0145 \text{ m}^2$$

The prototype wind speed selected, 15 mph, is

$$V_w = 6.7 \text{ m/sec}$$

The relationships for prototype shaft power, based on size only, is:

$$P_{sh}|_p = 36.3 \quad D_p^2 - 25.7 \quad D_p^{1.8} \qquad \text{watts}$$

The relationship for prototype shaft power can be modified to include Reynolds number influences by replacing D_2/D_1 with N_{Re_2}/N_{Re_1}. The expanded expression

for prototype flow losses, with $\nu_M = \nu_p$, is

$$\left(\frac{0.6 - C_{p_M}}{0.6 - C_{p_p}}\right) = \left(\frac{D_p V_p}{D_M V_M}\right)^{0.2}$$

The shaft power prediction equation, which includes size and velocity influences, is:

$$P_{sh}|_p = 36.3 \quad D_p^{\,2} - 35.3 \quad D_p^{\,1.8}$$

Prototype wheel diameters, for 4 power levels, were calculated using the above two models and a prototype wind velocity of 6.7 m/sec. The results, for a prototype operating at the optimum speed ratio of 0.42, are tabulated below.

Turbine Shaft Power kW	Turbine Rotor Diameter meters	
	Loss $\sim D^{0.2}$	Loss $\sim (DV)^{0.2}$
3	12	14
9	20	23
30	36	39
100	63	69

Conclusions and Recommendations

The normalized performance of the K Model WWT is plotted on Figure 21 with the ideal propeller windmill performance and the measured performance curves for other current windmill designs. The WWT performance is almost lost in the lower left hand corner of the plot. The WWT does not have much velocity ratio range, only up to ~ 1, and has very disappointing performance, $C_p \sim 0.02$, as compared to 0.4 for the high speed propeller designs.

Selecting the best single wind collection system from Figure 20, the wheel top of the Model K, and adding this to the comparative performance map, Figure 21, offers little encouragement. The wheel-top-only peak C_p was only 0.04 to 0.044. And the effectiveness of the one collector system design is poor for a large structure was required to support a small collector area.

The advantages of mechanical strength and safety are inherent to the WWT housed rotor design. These advantages might be preserved in a competitive design if a radial in-flow rotor were available. This new rotor could be fed from a large collector designed to provide a uniform, symmetric flow to the rotor inlet. The rotor exhaust would leave axially and be swept out with the passing wind. Such a system, carefully designed, could rival the high speed propeller type turbines in performance. The major problem would be keeping the wind turbine design small and light enough that its installed cost would still be competitive.

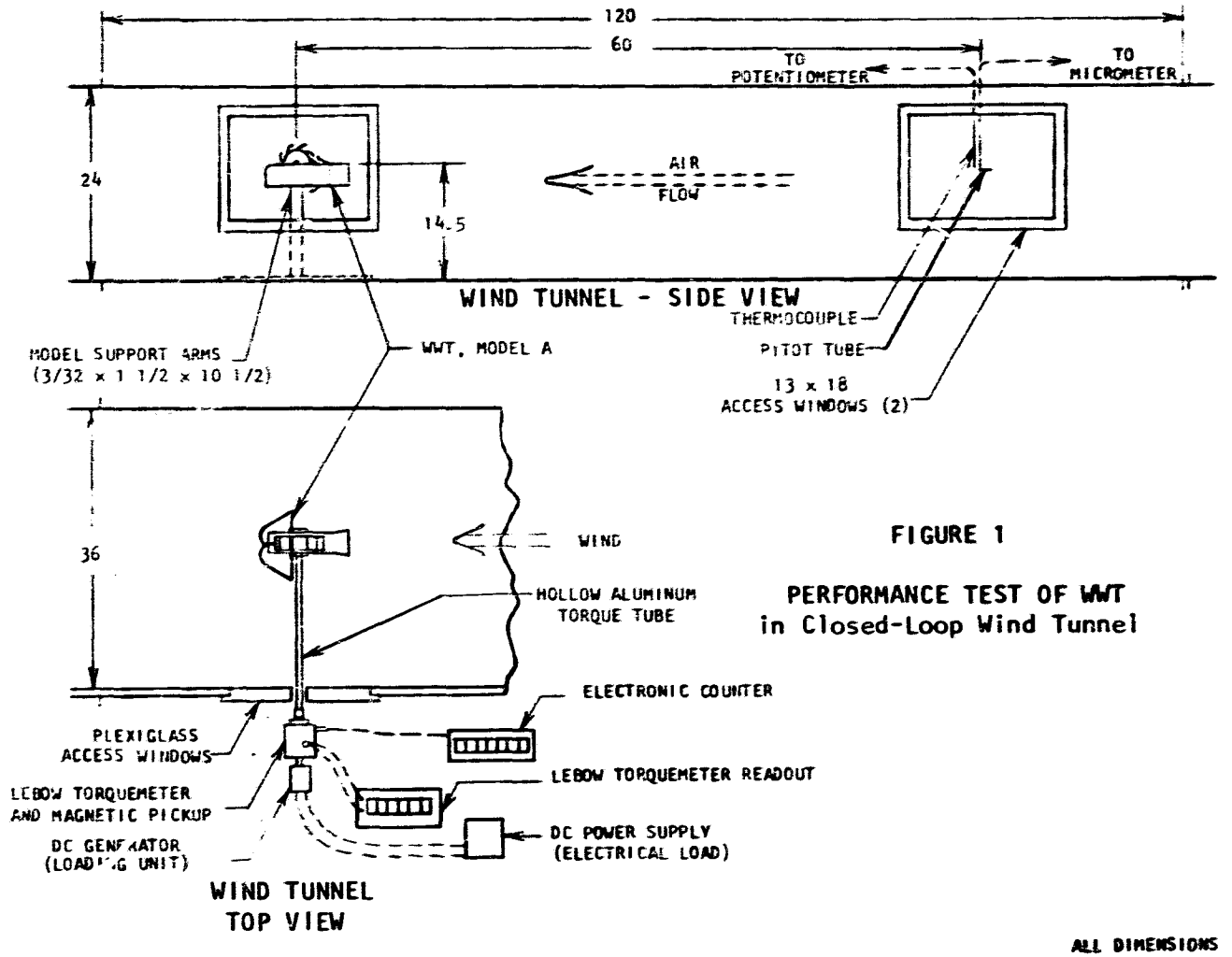
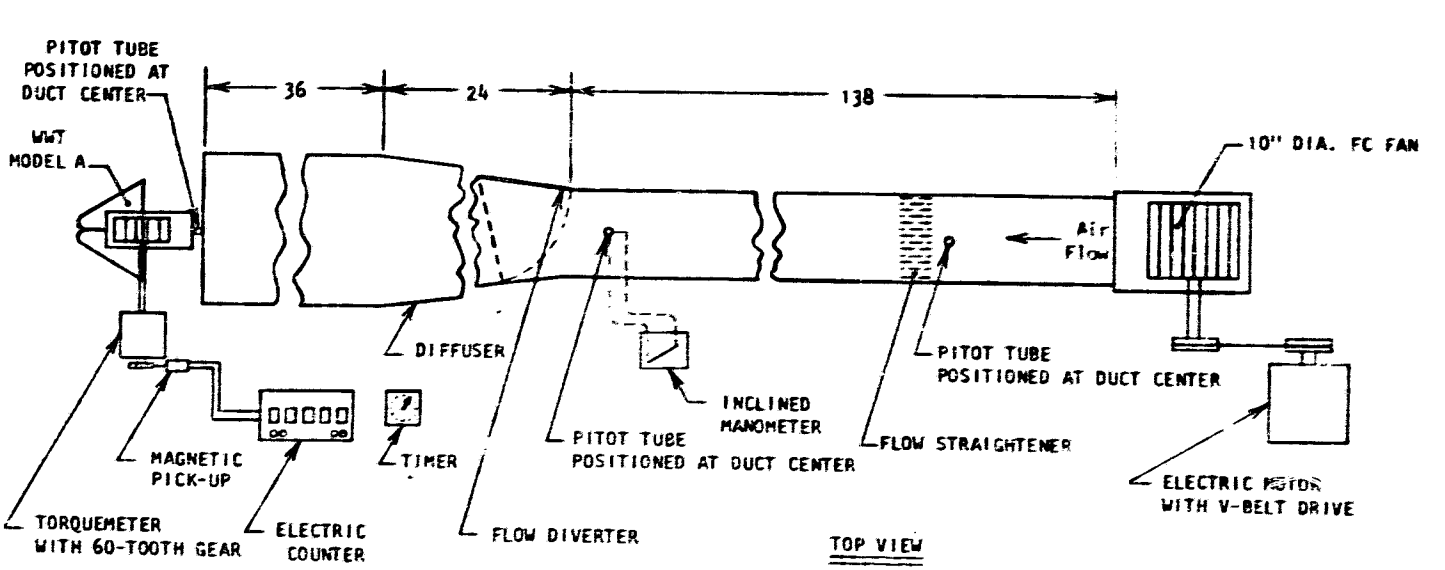
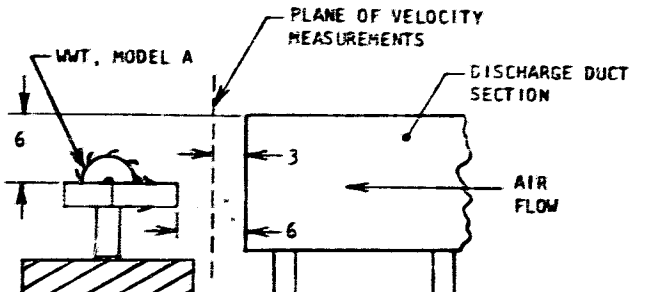


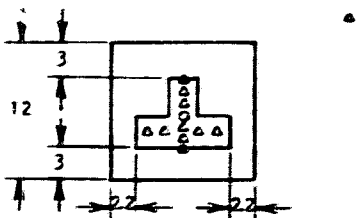
FIGURE 1

PERFORMANCE TEST OF WWT in Closed-Loop Wind Tunnel

ALL DIMENSIONS IN INCHES







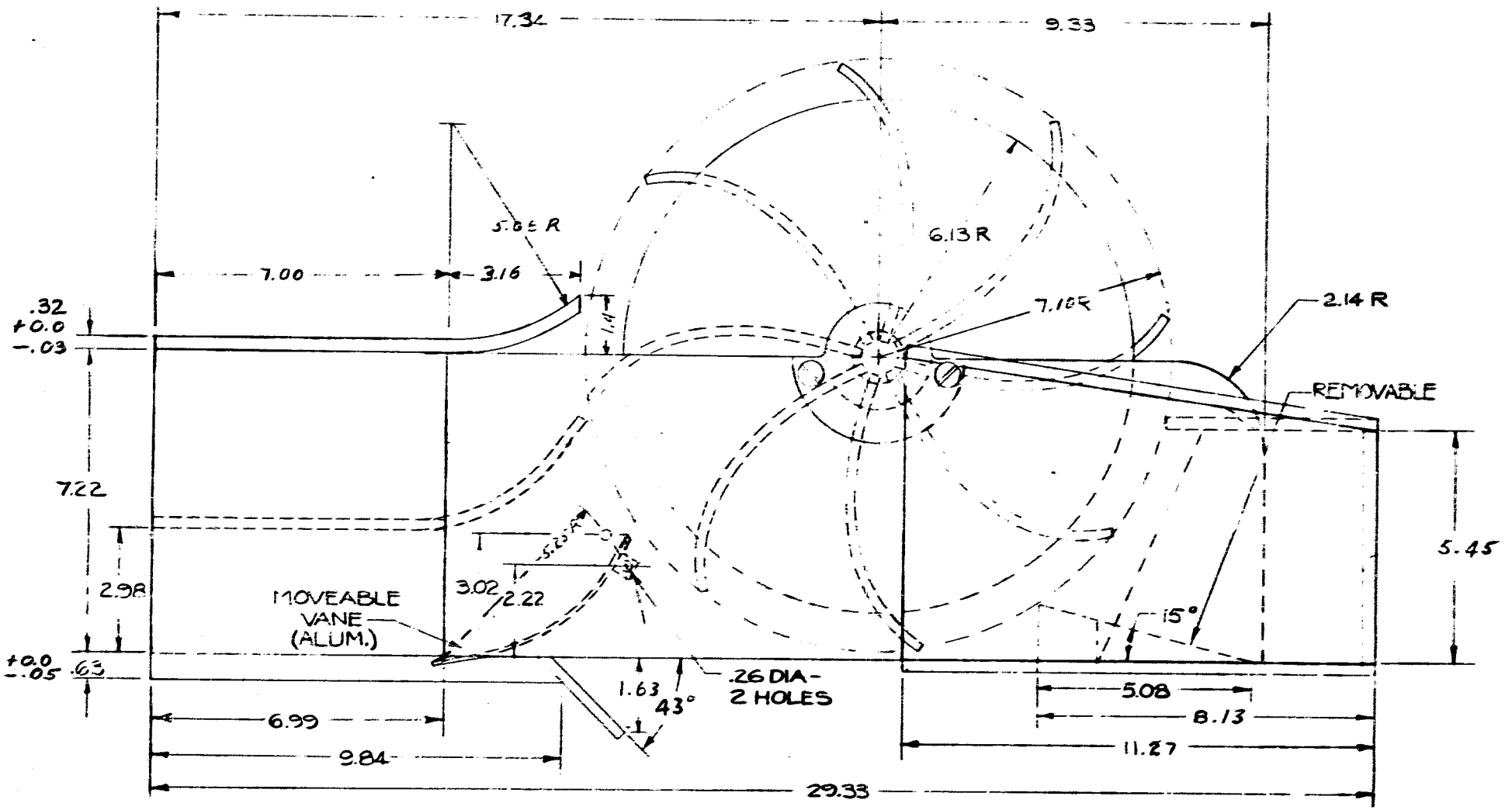
o PITOT TUBE

• ANEMOMETER TEST POINTS SPACED ON 1" CENTERS VERTICALLY AND 1½" CENTERS HORIZONTALLY

FIGURE 2

ALL DIMENSIONS IN INCHES

BLOW THROUGH WIND TUNNEL
Used for Spin-Up and Spin-Down Tests

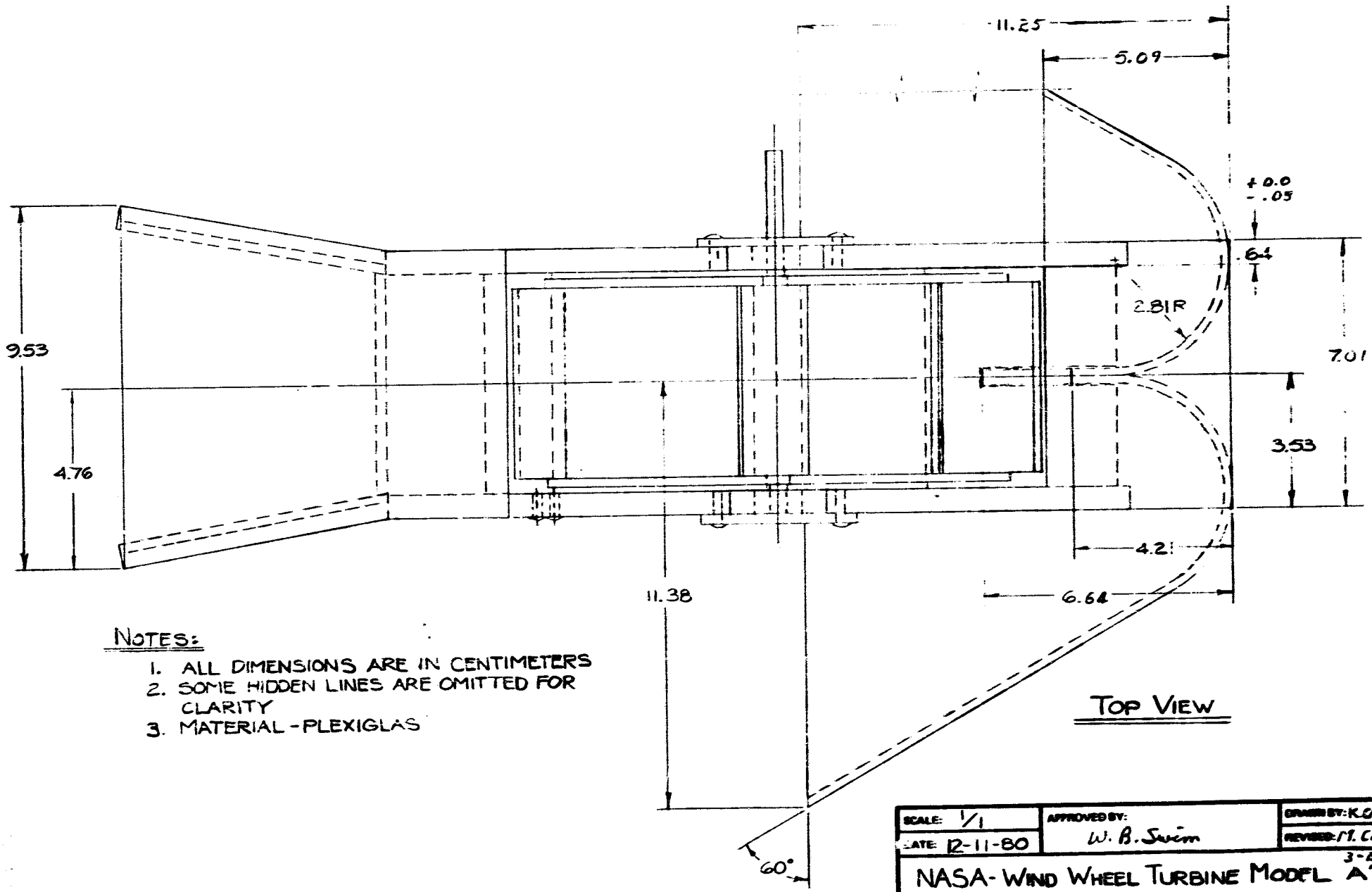


FOR NOTES SEE TOP VIEW

LEFT SIDE VIEW

SCALE: 1/1	APPROVED BY: W.B. Lucien	DRAWN BY: K. CARROLL
DATE: 12-11-80		REVISED: M. Collick 3-20-81
NASA- WIND WHEEL TURBINE MODEL 'A'		
TENN. TECH UNIV. DEPT. OF MECH. ENGR.		DRAWING NUMBER WT-1

FIGURE 3 MODEL A WWT SIDE VIEW



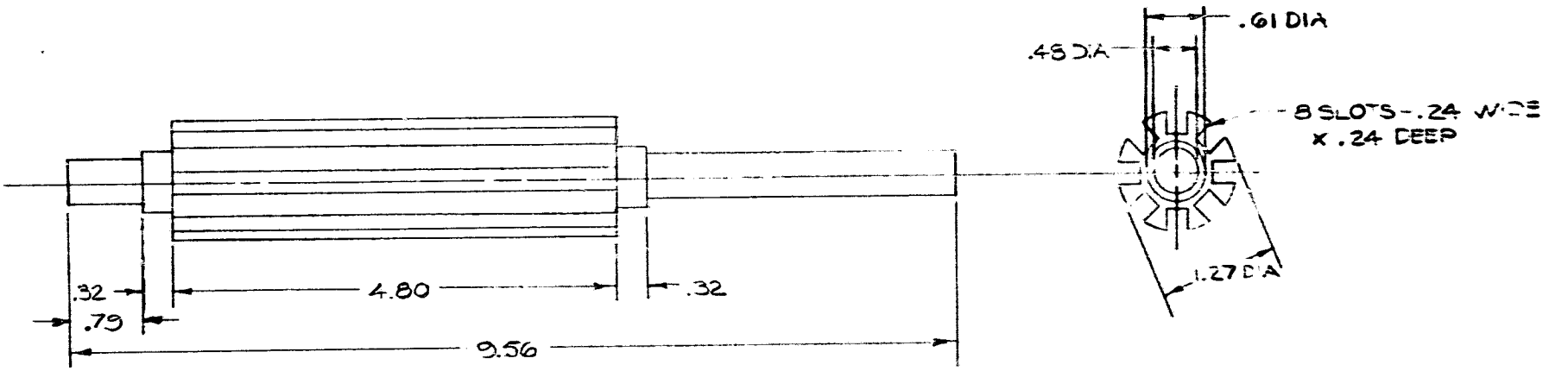
NOTES:

1. ALL DIMENSIONS ARE IN CENTIMETERS
2. SOME HIDDEN LINES ARE OMITTED FOR CLARITY
3. MATERIAL - PLEXIGLAS

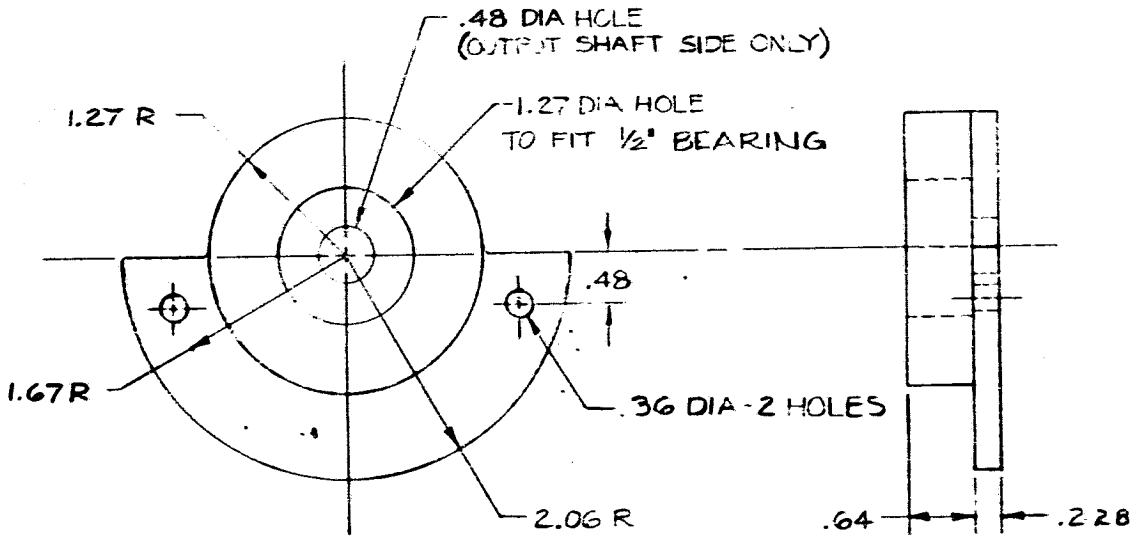
TOP VIEW

SCALE: 1/1	APPROVED BY: W. B. Swim	DRAWN BY: K. CARROLL
DATE: 12-11-80		REVISED: M. Collier 3-26-81
NASA-WIND WHEEL TURBINE MODEL A'		
TENN. TECH. UNIV. DEPT. OF MECH. ENGR		DRAWING NUMBER WT-2

FIGURE 4 MODEL A WWT TOP VIEW



TURBINE SHAFT



BEARING HOLDER - 2 REQ'D

NOTES:

1. ALL DIMENSIONS ARE IN CENTIMETERS
2. MATERIALS:
   SHAFT - ALUMINUM
   HOLDER - PLEXIGLASS

SCALE: 2/1	APPROVED BY: W.B. Swinson	DRAWN BY: K. CARROLL
DATE: 12-11-80		REVISED: M. COLLIER 3-26-81
NASA - WIND WHEEL TURBINE MODEL A		
TENN. TECH. UNIV. DEPT. OF MECH ENGR		DRAWING NUMBER WT-3

FIGURE 5 MODEL A WWT ROTOR DETAILS

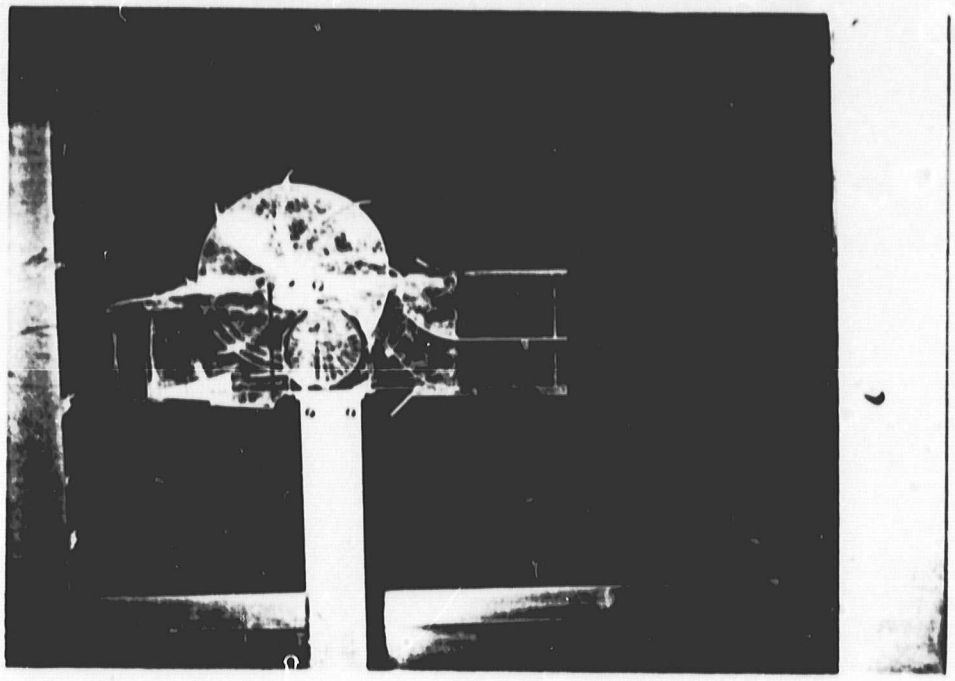


FIGURE 6

MODEL A WWT WIND TURBINE
Mounted in Wind Tunnel

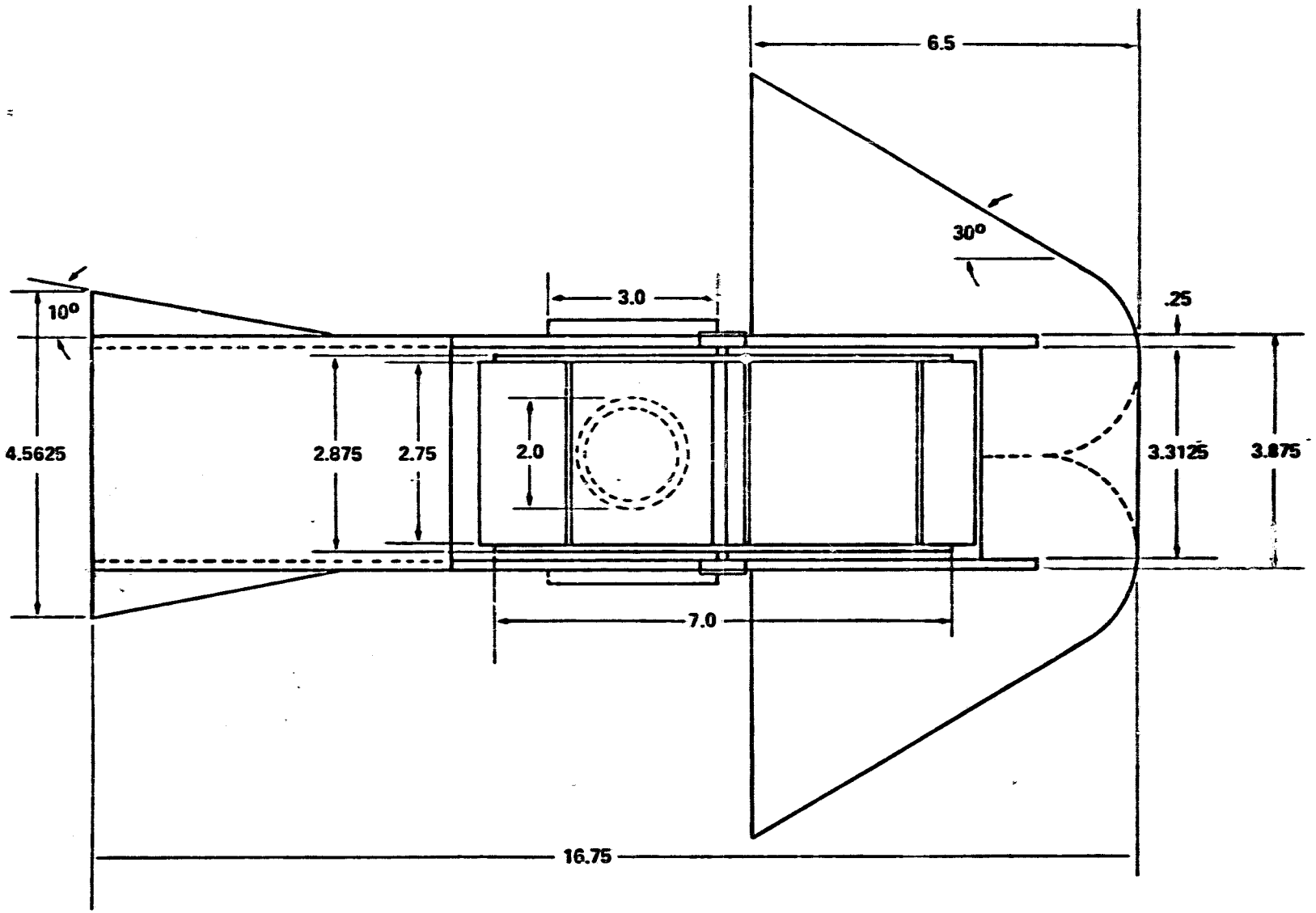


FIGURE 7 MODEL K WWT TOP VIEW

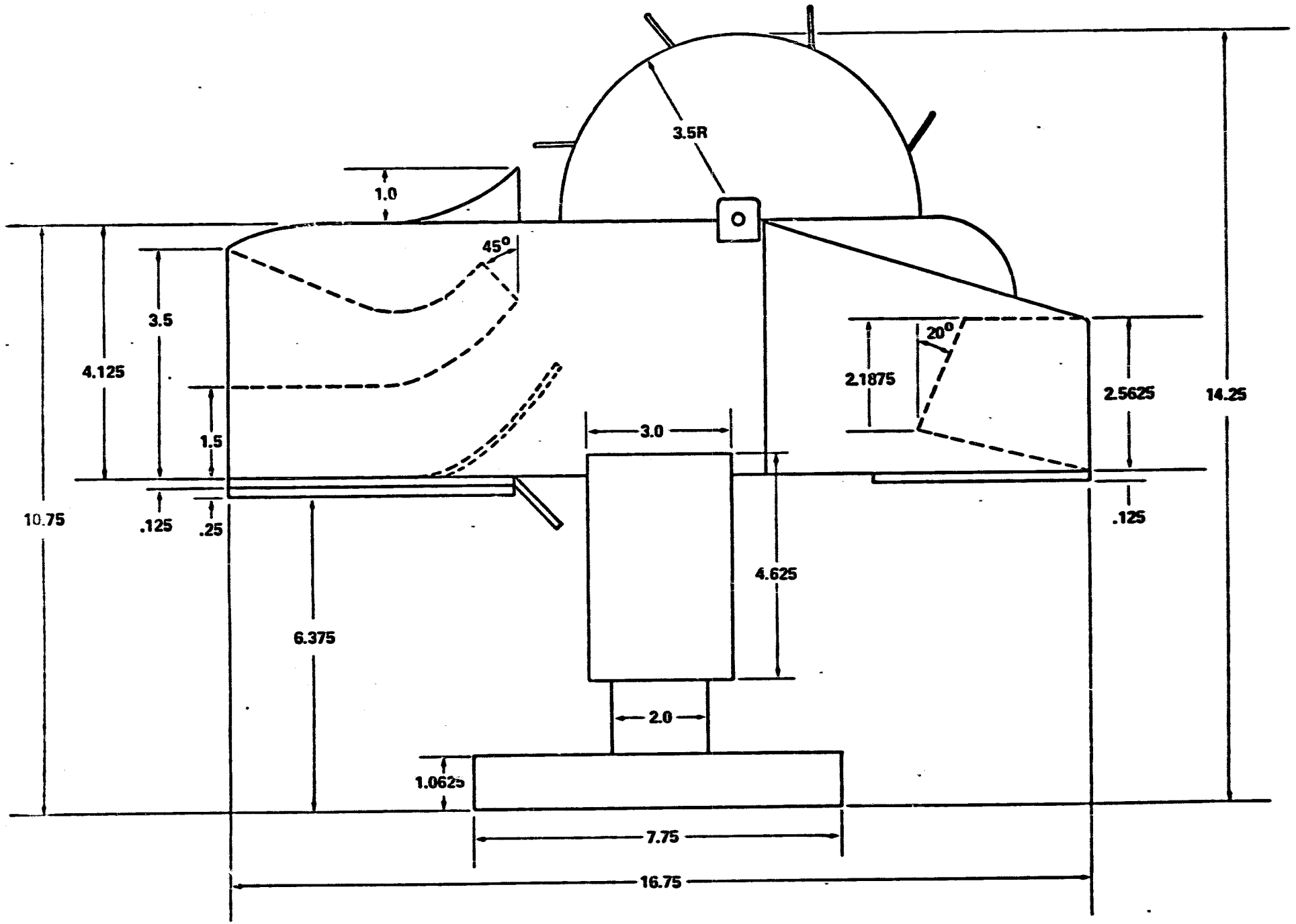


FIGURE 8 MODEL K WWT SIDE VIEW

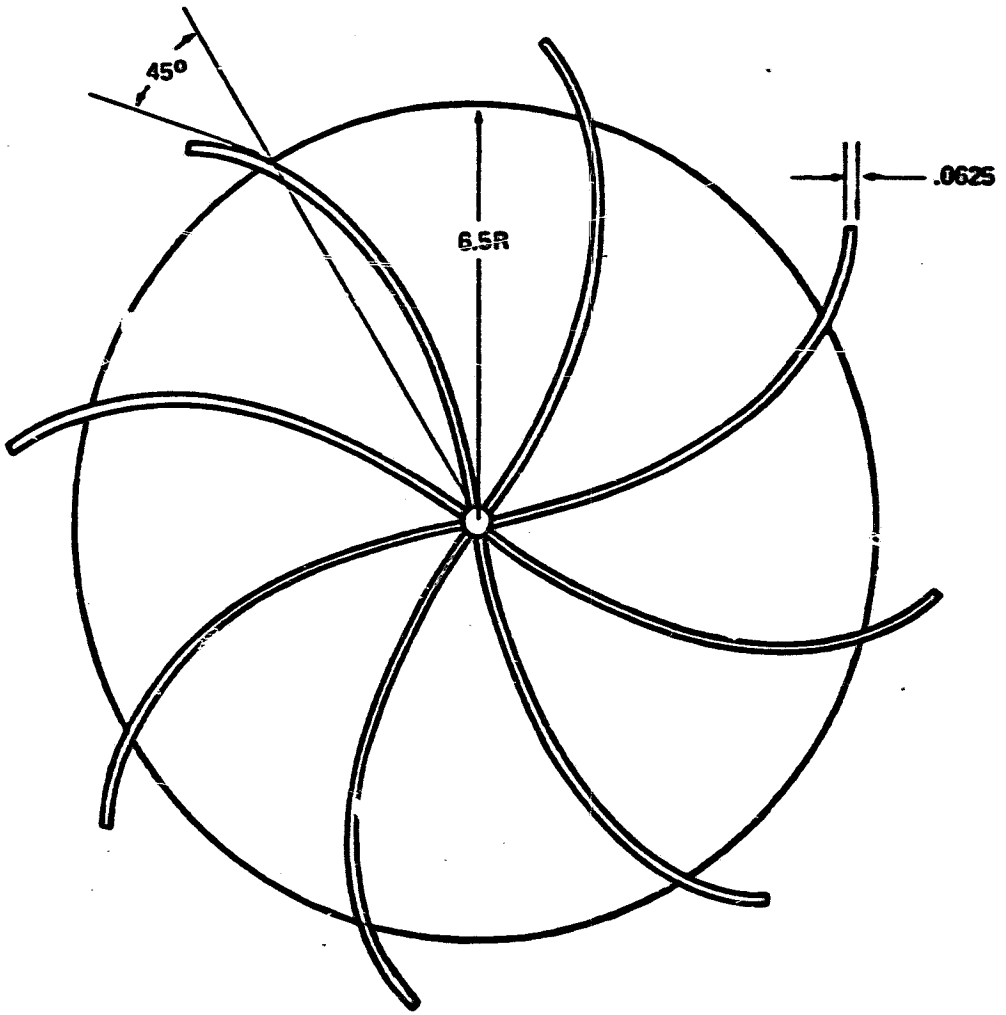


FIGURE 9 MODEL K WWT ROTOR

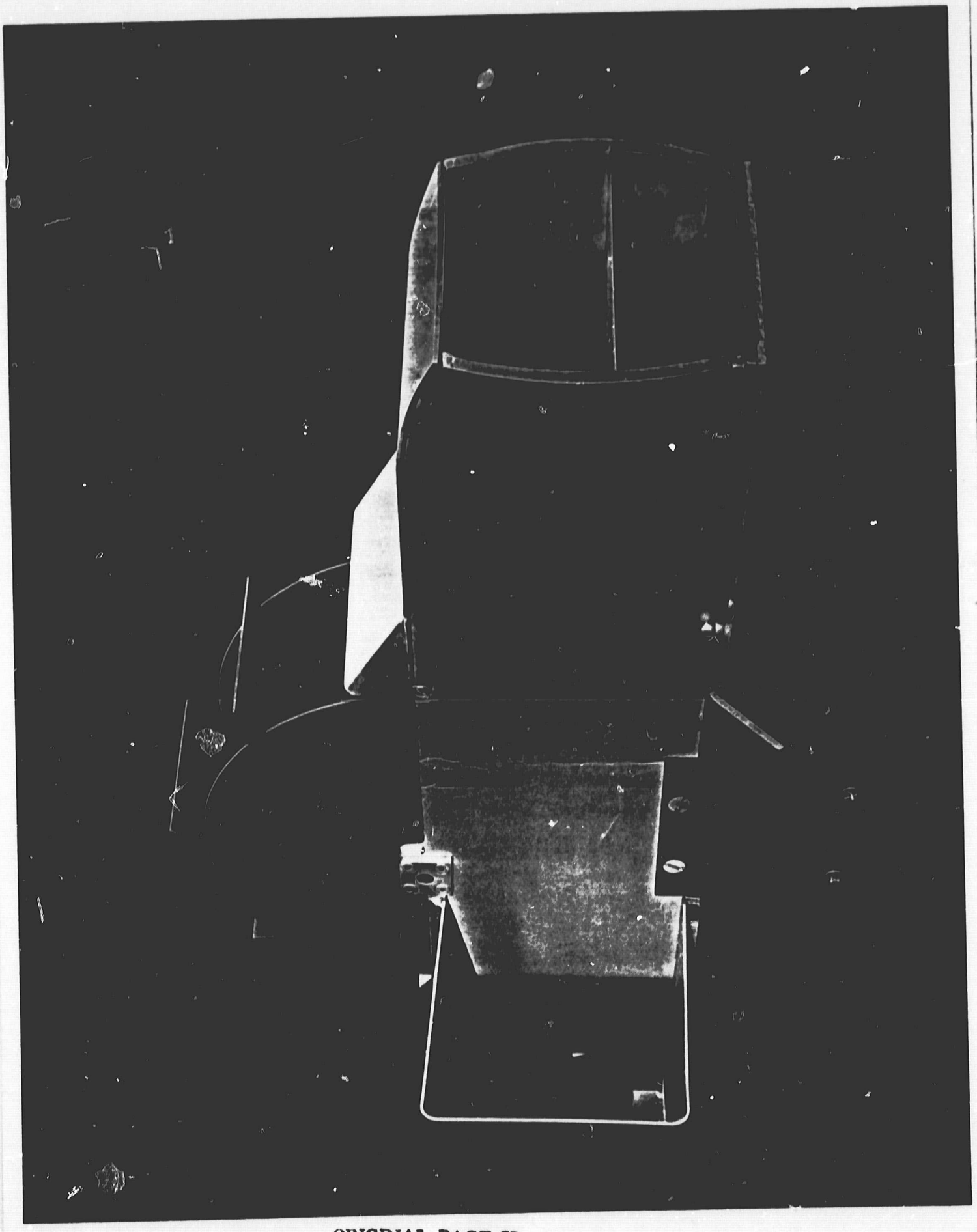


FIGURE 10 MODEL K WT WIND TURBINE

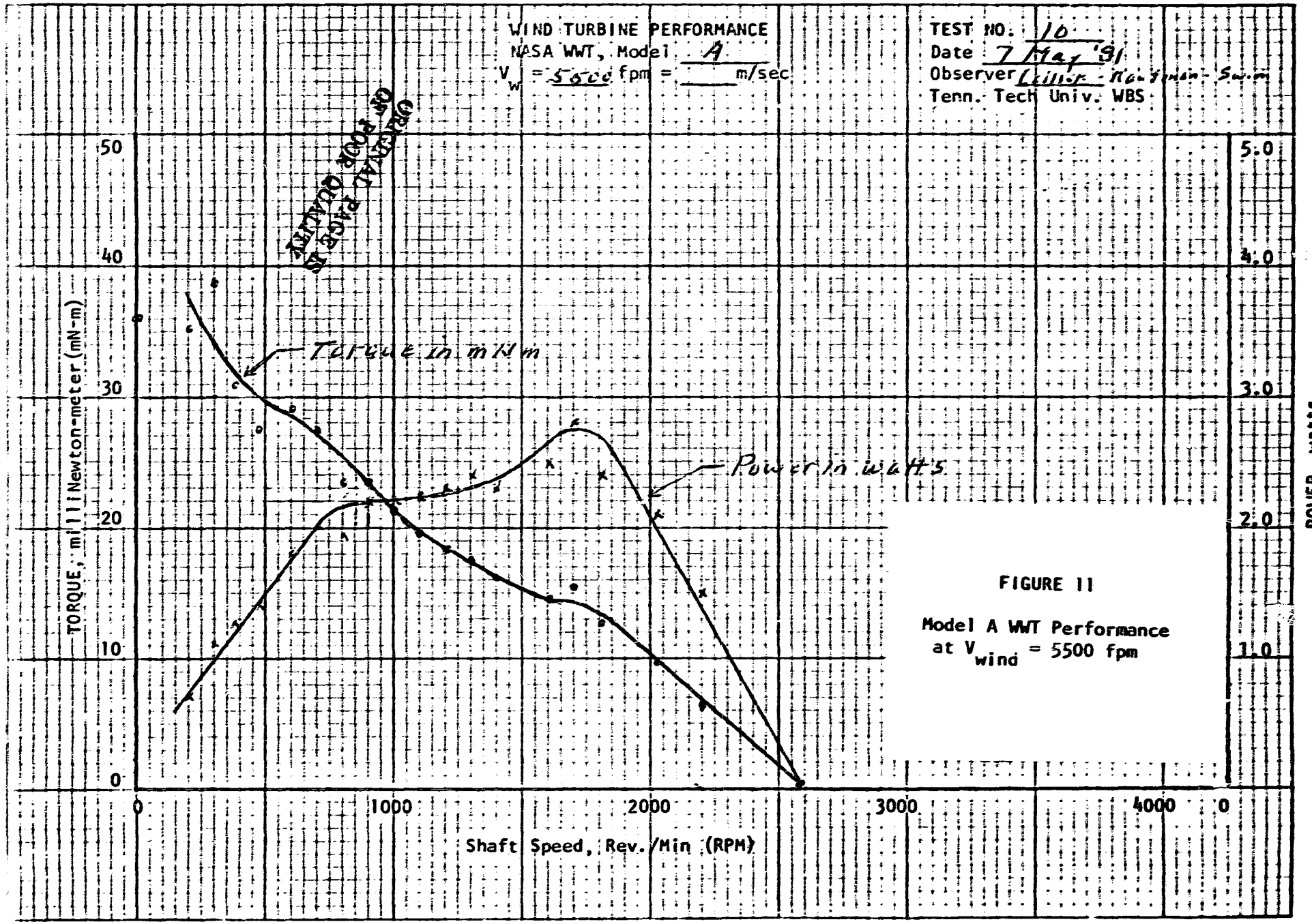


FIGURE 11

Model A WWT Performance at V_{wind} = 5500 fpm

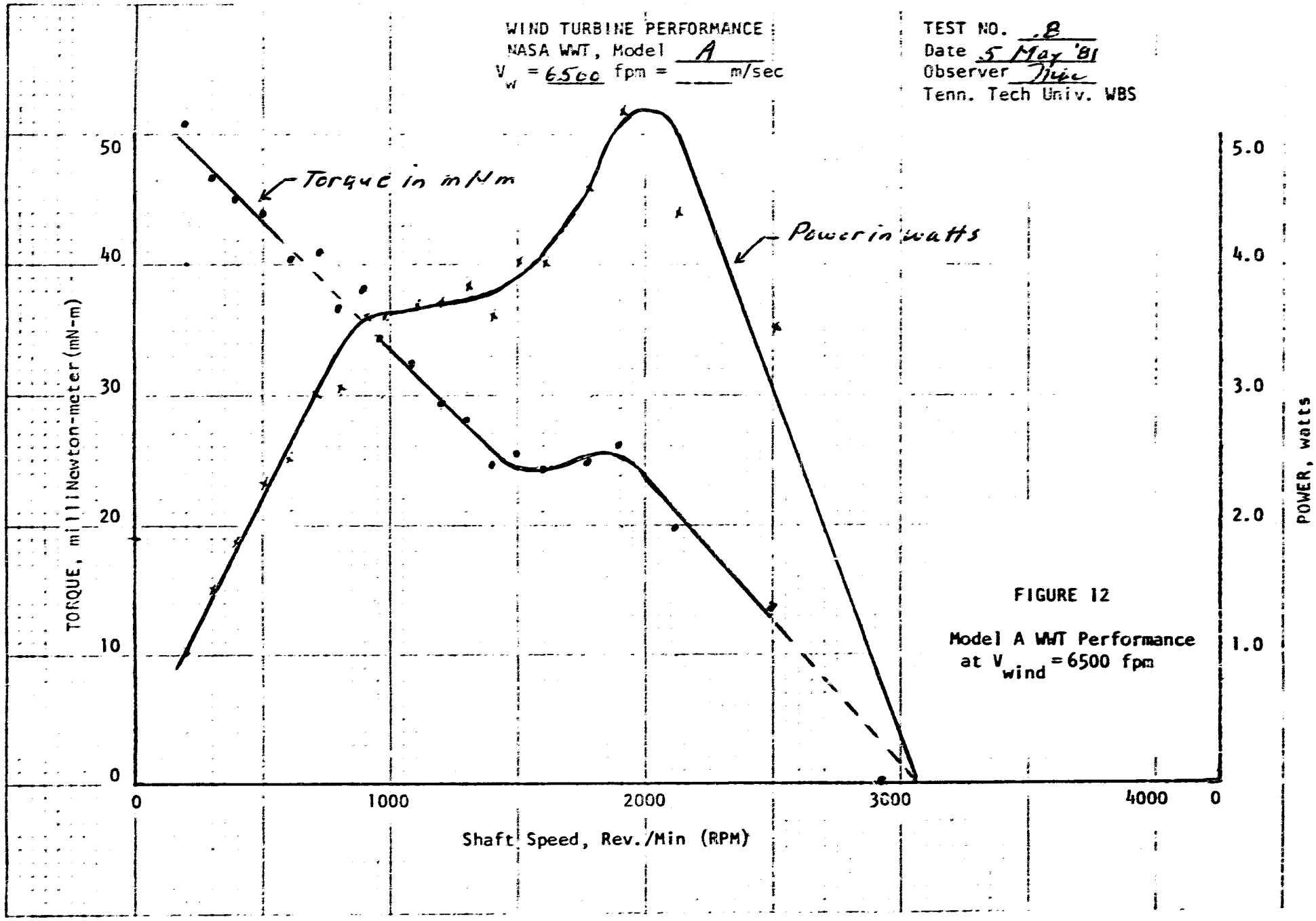


FIGURE 12

Model A WWT Performance at V_{wind} = 6500 fpm

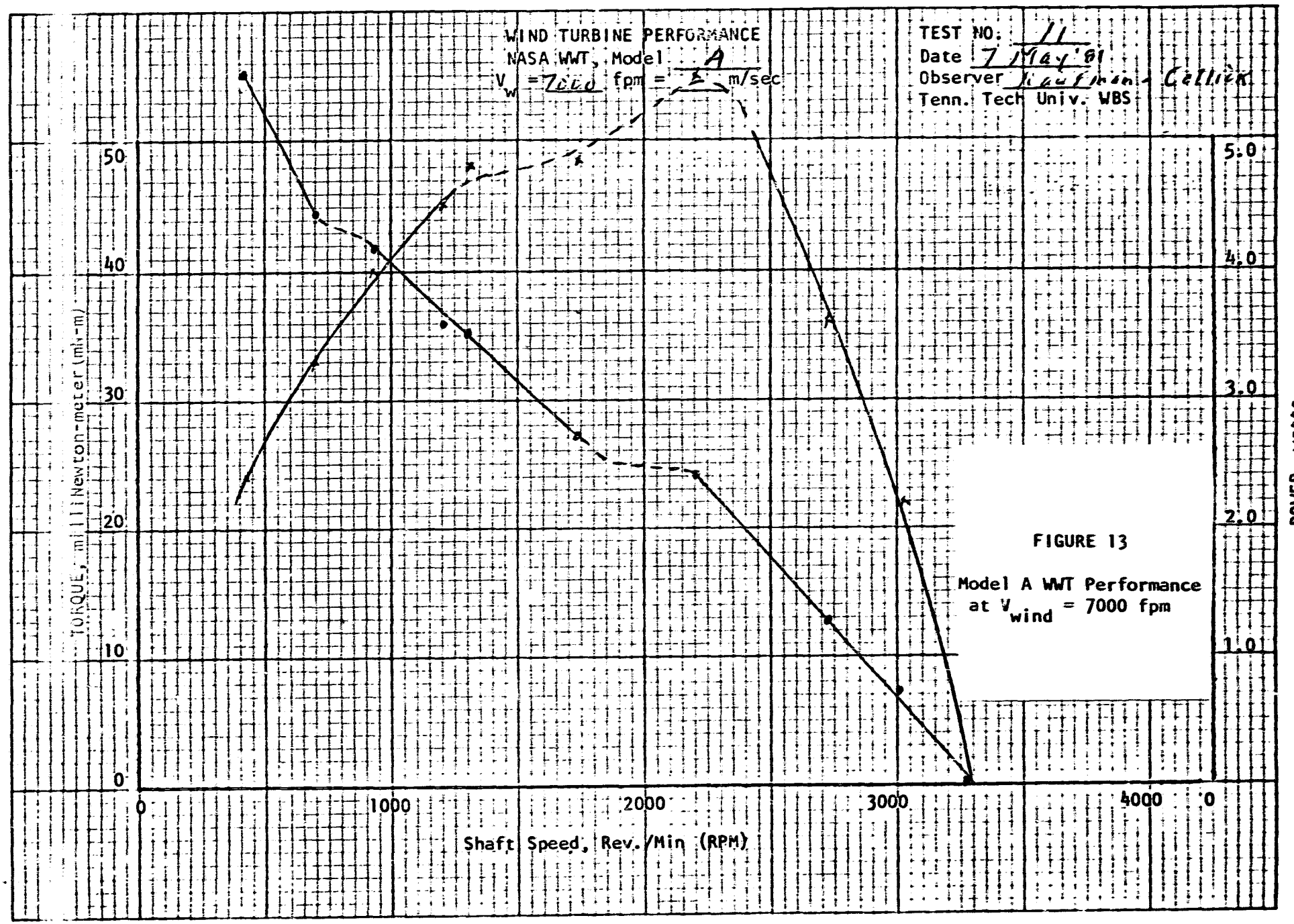


FIGURE 13

Model A WWT Performance at V_{wind} = 7000 fpm

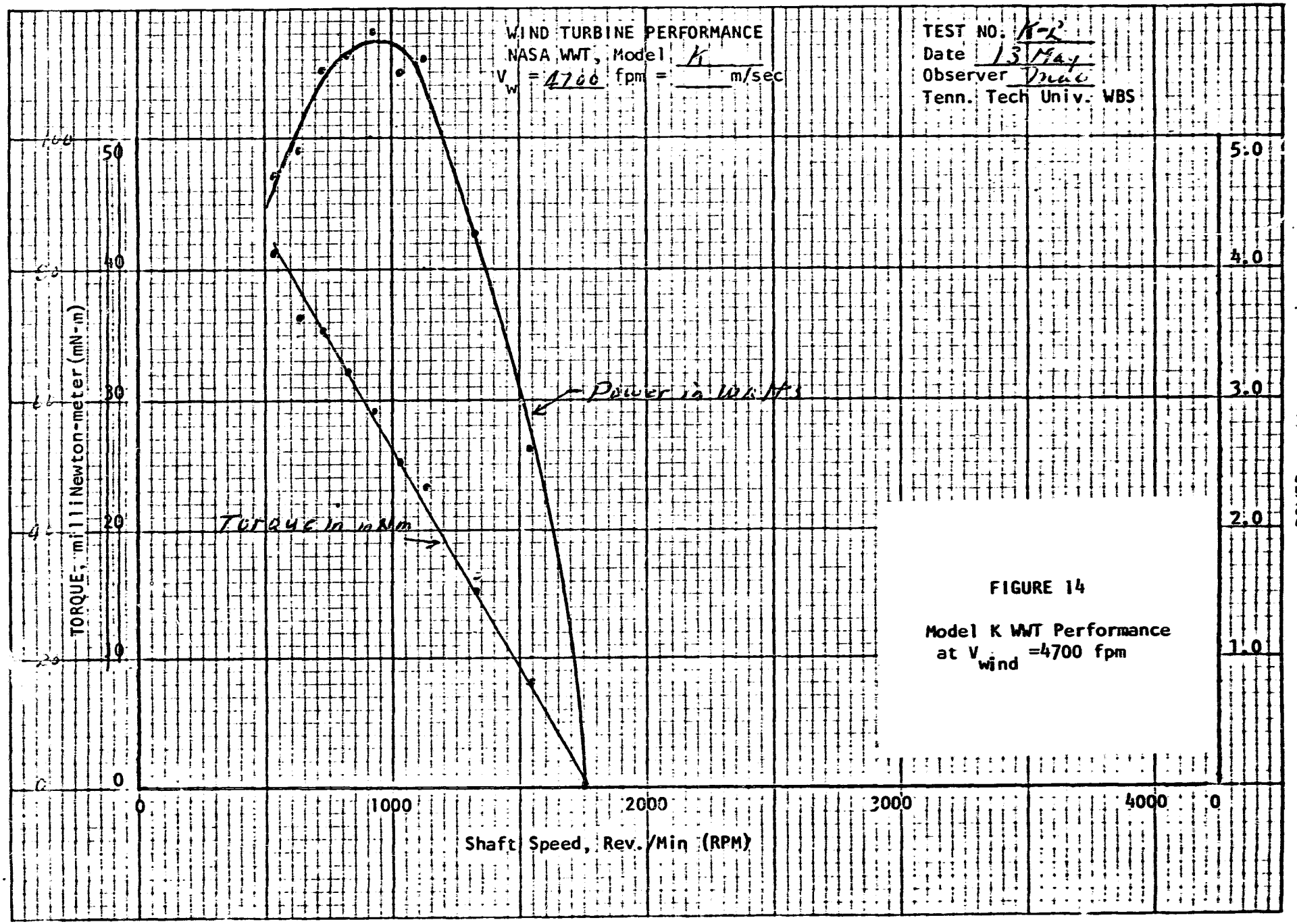


FIGURE 14

Model K WWT Performance at V_{wind} =4700 fpm

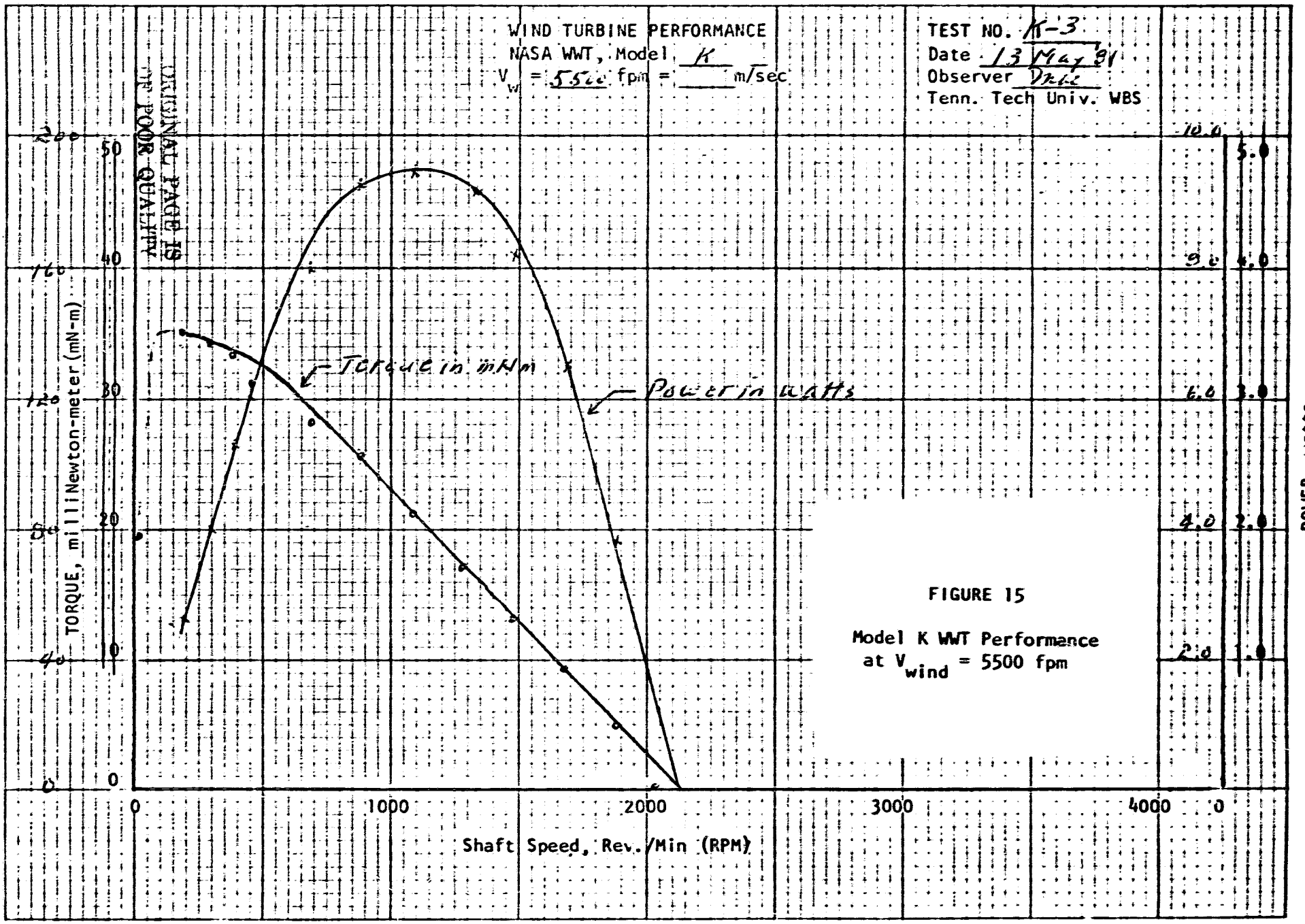


FIGURE 15

Model K WWT Performance at V_{wind} = 5500 fpm

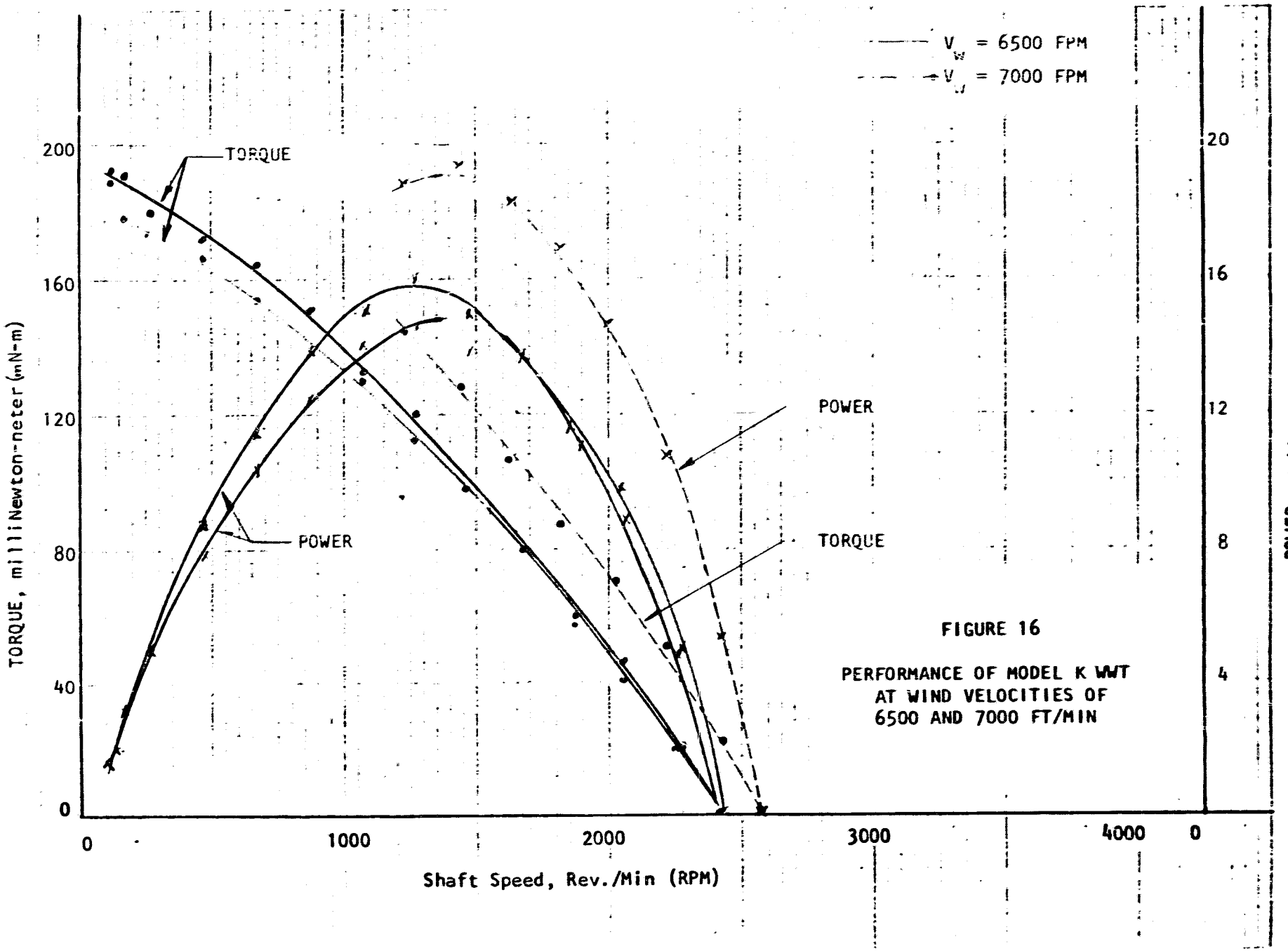
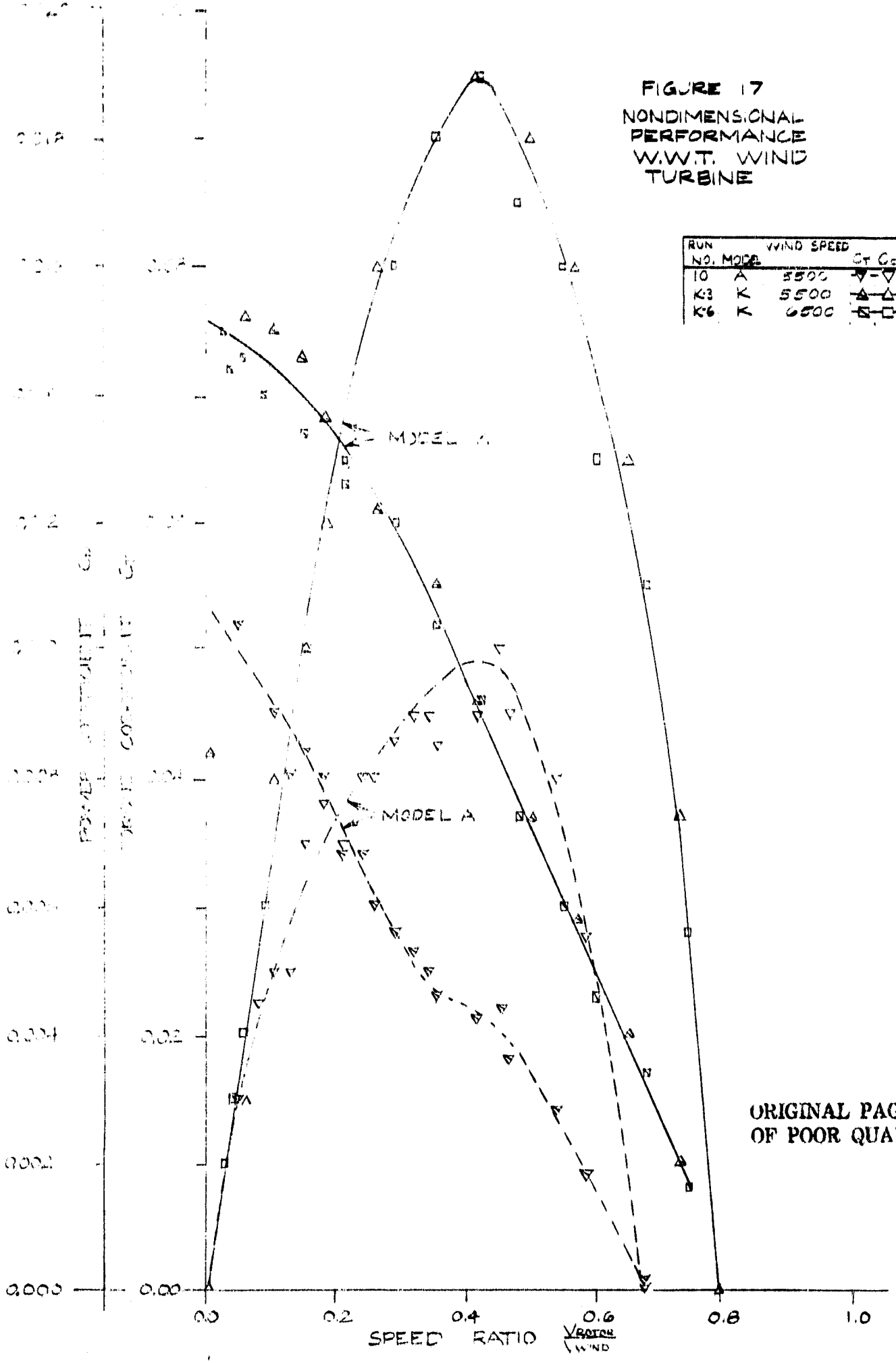


FIGURE 16

PERFORMANCE OF MODEL K WWT
AT WIND VELOCITIES OF
6500 AND 7000 FT/MIN

FIGURE 17
NONDIMENSIONAL PERFORMANCE W.W.T. WIND TURBINE

RUN NO.	MODEL	WIND SPEED	C_T C_E
10	A	5500	▽–▽
K-3	K	5500	△–△
K-6	K	6500	□–□



ORIGINAL PAGE IS OF POOR QUALITY

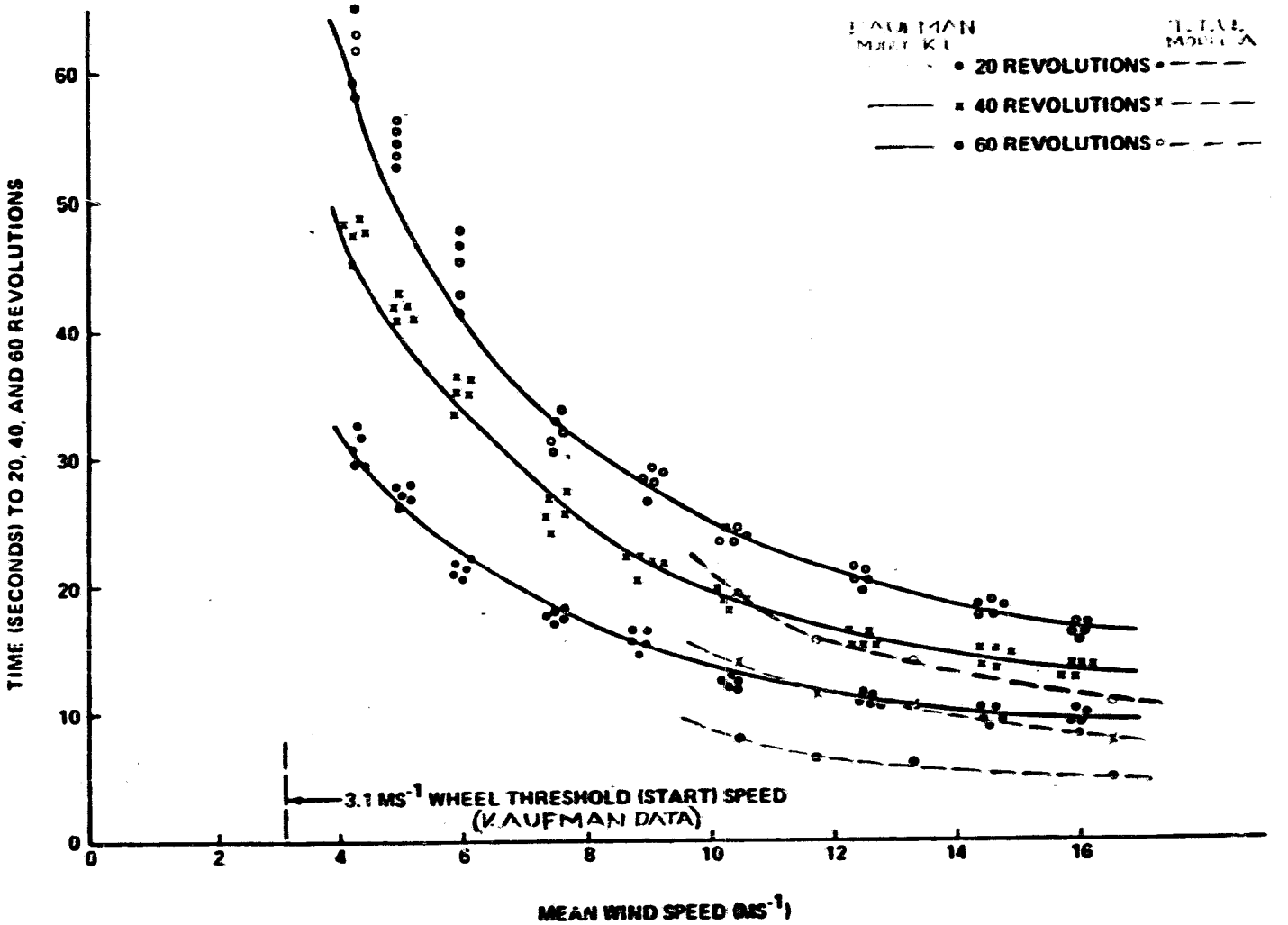


Figure 18 SPIN-UP TESTS - Time for WWT rotor to make 20, 40 and 60 revolutions versus mean wind speed

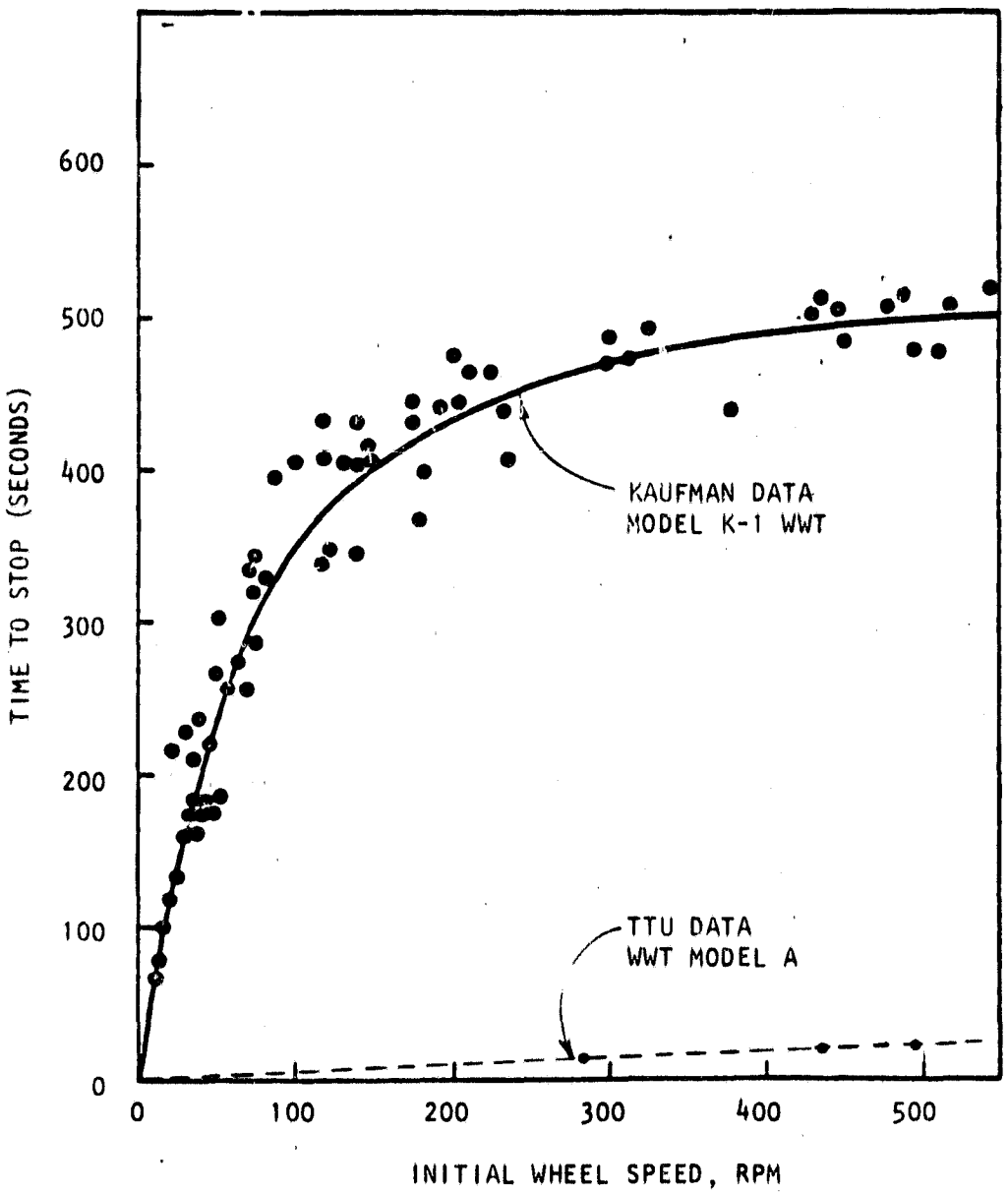


FIGURE 19 SPINDOWN TEST RESULTS

Time for WWT Rotor to stop versus initial rotor speed

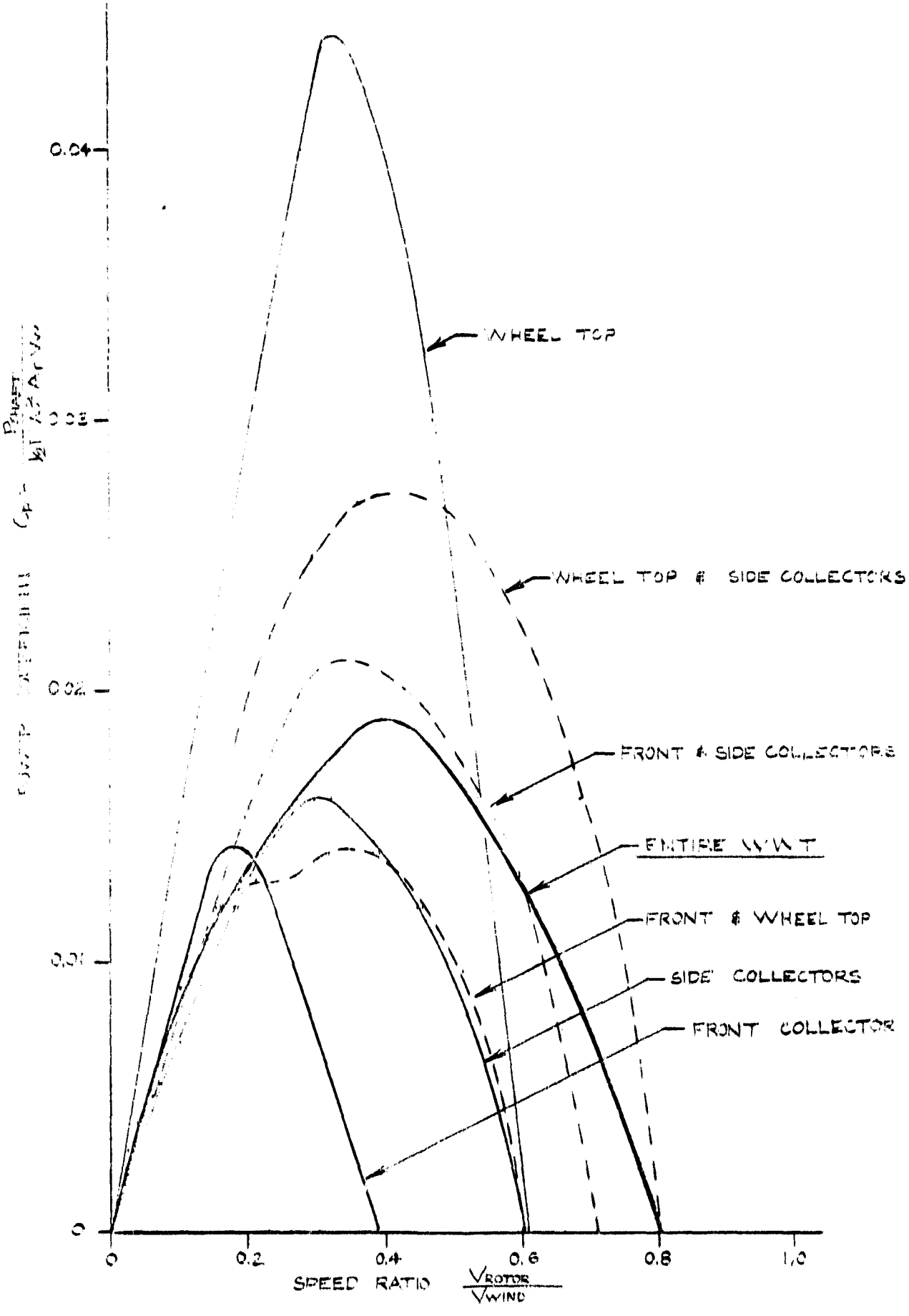


FIGURE 20 POWER COEFFICIENT FOR INDIVIDUAL WIND COLLECTOR SYSTEMS FOR MODEL K WWT
Based only on collector area open, V_{wind} = 6500 fpm

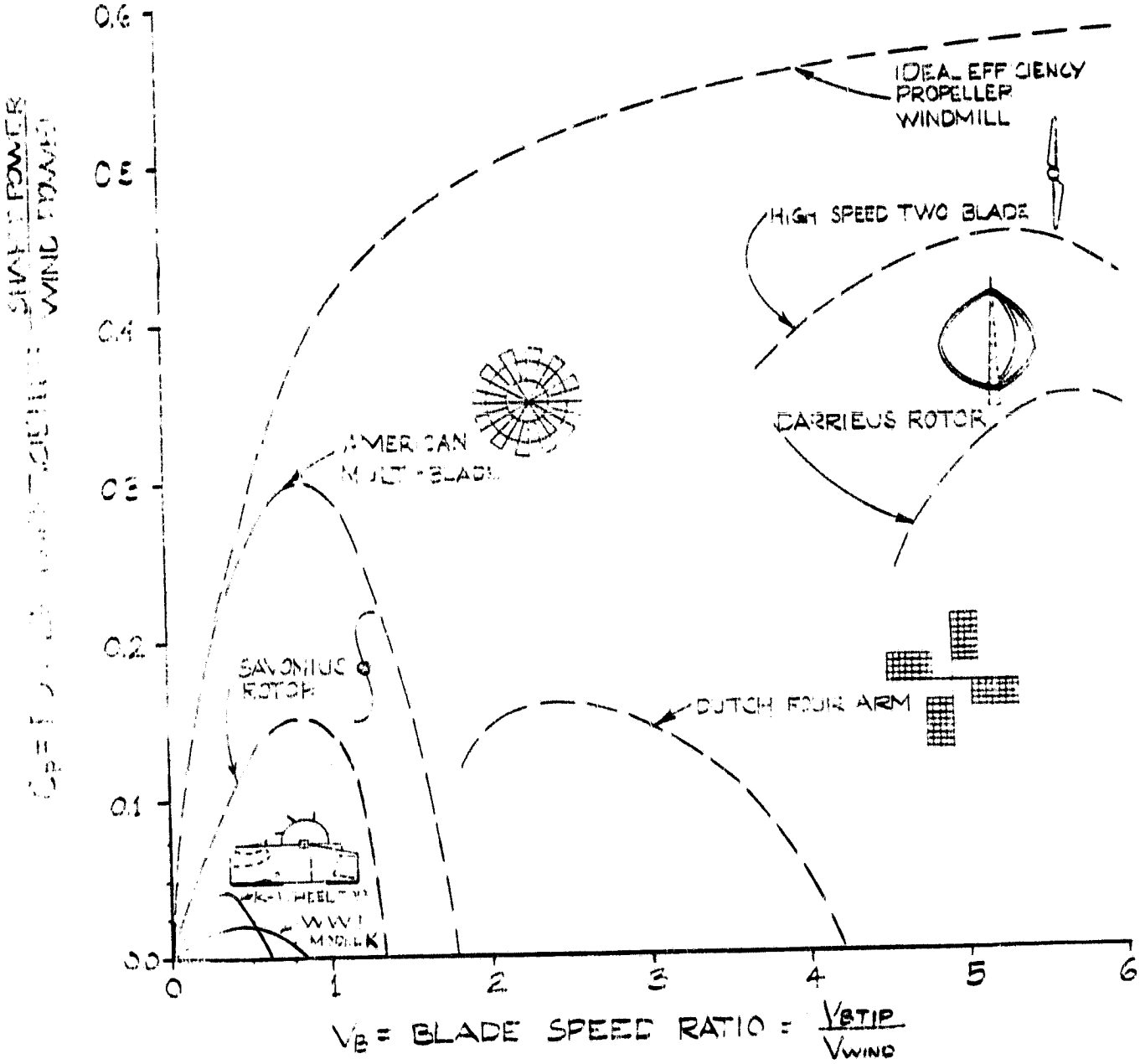


FIGURE 21 COMPARATIVE PERFORMANCE MAP
Power Coefficient Versus Speed Ratio

APPENDIX A
TEST DATA

Index of Data Sheets

Test No	Date	Model	Nominal Wind Speed ft/min	Description of Test
1	2/25/81	A	5500	Prony brake torque measurement
2	2/25/81	A	6500	" " " "
3	2/28/81	A	5500	Repeat of Test 1
4	3/2/81	A	6500	Repeat of Test 2
5	3/3/81	A	5500	Repeat of Test 1
6	3/4/81	A	6500	Repeat of Test 2
7	5/5/81	A	5500	Torquemeter readout
8	5/5/81	A	6500	" "
9	5/7/81	A	6500	" "
10	5/7/81	A	5500	Test with Kaufman
11	5/7/81	A	7000	Survey test with Kaufman
K-1	5/12/81	K	5500	Partial test - overloaded generator load
K-2	5/13/81	K	4700	Torquemeter readout, Friction brake load
K-3	5/13/81	K	5500	" " " " "
K-4	5/14/81	K	6500	" " " " "
K-5	5/22/81	K	4000	Stall torque tests
K-6	5/22/81	K	6500	Repeat of K-4
K-7	5/22/81	K	7000	Survey test only
K-8	6/19/81	K	5500	Side collectors only open
K-9	6/19/81	K	6500	" " " "
K-10	6/22/81	K	5500	Wheel top only open
K-11	6/22/81	K	6500	" " " "
K-12	6/22/81	K	5500	Front and wheel top open
K-13	6/22/81	K	6500	" " " " "
K-14	6/23/81	K	5500	Front inlet only open
K-15	6/23/81	K	6500	" " " "
K-16	6/23/81	K	5500	Front and side collectors open
K-17	6/23/81	K	6500	" " " " "
K-18	6/23/81	K	5500	Side collectors and wheel top open
K-19	6/24/81	K	6500	" " " " " "

Sheet 1

TTU-NASA WWT TEST DATA

Test No. 1
Date 25 Feb. 91

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) D. A. Cochran T$_{room}$ 75 °F; P$_{Bar}$ 29.26 "Hg; T$_{Bar}$ 25.0 °C
Dwyer 5:56c 19 29.24 25.5

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_W fpm	Velocity V_W m/s	Torque T mN·m	Power P Watts
1	s	...	1.827	.95	90	2386	1.70			3.33	.83
	f										
2	s		1.824	.948	92	2268	2.60			5.10	1.21
	f										
3	s		1.819	.945	92	1966	5.30			10.40	2.14
	f										
4	s		1.819	.940	93	1810	6.50			12.74	2.41
	f										
5	s		1.815	.940	93	1657	8.05			15.80	2.74
	f										
6	s		1.811	.940	94	1515	8.50			16.70	2.65
	f										
7	s		1.809	.938	94	1255	8.40			16.46	2.16
	f										
8	s		1.809	.935	97	1121	9.55			18.72	~~3.68~~ 2.2
	f										
9	s		1.811	.945	97	946	11.20			21.95	2.17
	f										
10	s		1.804	.930	97	820	12.30			24.11	2.07
	f										
11	s		1.804	.935	97	700	13.10			25.67	1.88
	f										
12	s		1.804	.935	98	555	13.40			26.30	1.53
	f										
13	s		1.804	.935	98	447	14.55			28.52	1.33
	f										
14	s		1.804	.935	98	371	15.40			30.20	1.17
	f										
15	s		1.803	.935	98	245	16.60			32.53	.83
	f										
16	s		1.803	.935	98	158	~~16.60~~ 17.0			33.32	.55
	f										
17	s		1.803	.935	98	102	17.40			34.10	.34
	f										

COMMENTS: _____

Sheet 2

Test No. 1
Date 23 Feb. 81

TTU-NASA WWT TEST DATA

Performance Test of Model ____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} _____ °F; P_{Bar} _____ "Hg; T_{Bar} _____ °C

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_W fpm	Velocity V_W m/s	Torque T mN·m	Power P Watts
0	s		1.837	.960	96	2560	Arm removed				
X	f		〃	〃	〃	〃					
18	s		1.802	.935	98	54	17.40			34.10	.19
2	f		〃	〃	〃	〃	〃				
19	s		1.802	.935	98	0	16.00			31.36	
3.	f		〃	〃	〃	〃	〃				
20	s		1.802	.935	98	2554	Arm removed				
4	f										
5	s										
	f										
6	s										
	f										
7	s										
	f										
8	s										
	f										
9	s										
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. _____ Date 5-3-84

Performance Test of Model _____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} 75 °F; P_{Bar} 29.19 "Hg; T_{Bar} 26.2 °C

Blower 6500 "2400 rpm

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.574	1.33	87	3020	Arm removed			0	
	f		2.565	1.33	"						
2	s		2.554	1.32	91	2920	1.30			2.54	.78
	f		"	"	"	"	"				
3	s		2.544	1.32	96	2752	2.30			4.51	1.31
	f		"	"	"	"	"				
4	s		2.522	1.30	96	2686 2446	4.25			8.33	2.30
	f		"	"	"	"	"				
5	s		2.536	1.30	96	2486	5.6			11.0	2.86
	f		"	"	"	"	"				
6	s		2.533	1.30	96	2330	7.05			13.81	3.37
	f		"	"	"	"	"				
7	s		2.530	1.30	100	2172	9.0			17.64	4.01
	f		"	"	"	"	"				
8	s		2.519	1.30	100	2006	10.3			20.20	4.24
	f		"	"	"	"	"				
9	s		2.519	1.30	100	1854	11.7			22.93	4.45
	f		"	"	"	"	"				
10	s		2.519	1.30	101	1723	11.85			23.22	3.58
	f		"	"	"	"	"				
11	s		2.515	1.30	101	1593	11.60			22.73	3.67
	f		"	"	"	"	"				
12	s		2.518	1.30	101	1352	13.10			25.67	3.63
	f		"	"	"	"	"				
13	s		2.518	1.30	101	1139	15.00			29.40	3.51
	f		"	"	"	"	"				
14	s		2514	1.30	102	1029	16.35			32.04	3.45
	f		"	"	"	"	"				
15	s		2.514	1.30	102	830	18.11			35.50	3.08
	f		"	"	"	"	"				
16	s		2.514	1.30	105	764	18.25			35.80	2.86
	f		"	"	"	"	"				
17	s		2.505	1.30	105	612	18.60			36.50	2.34
	f		"	"	"	"	"				

COMMENTS: _____

			rpm	gr	Tor.	Watts
2.505	1.30	105	501	18.85	36.90	1.94
2.505	1.30	"	402	18.80	36.85	1.55
2.505	1.30	"	302	19.30	37.83	1.19
2.510	1.30	"	204	19.65	38.51	.82
2.510	1.30	"	155	20.05	39.30	.64
2.510	1.30	"	115	21.80	42.73	.51
2.502	1.30	"	61	22.00	43.12	.27
2.501	1.30	"	40	22.80	44.69	.019
~~2.501~~	~~1.30~~	—	0	12.5	24.50	0
~~2.504~~	~~1.30~~	—	3010	Arm removed		

TTU-NASA WWT TEST DATA

Date 28 Feb. '91

Performance Test of Model _____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} 79 °F; P_{Bar} 29.17 "Hg; T_{Bar} 29.5 °C

Dwyer 5500 - 5400 82 29.19 29.5

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.810	0.90	85	2501	0			0	0
	f										
2	s		1.801	0.90	85	2303	1.60			3.14	.76
	f										
3	s		1.787	0.90	85	2180	2.75			5.39	1.23
	f										
4	s		1.804	0.90	88	1975	4.55			8.92	1.84
	f										
5	s		1.797	0.88	88	1816	6.00			11.76	2.24
	f										
6	s		1.784	0.89	90	1654	8.00			15.68	2.72
	f										
7	s		1.790	0.87	93	1453	8.00			15.68	2.38
	f										
8	s		1.789	0.87	93	1233	8.30			16.27	2.10
	f										
9	s		1.779	0.87	93	1124	9.45			18.52	2.18
	f										
10	s		1.779	0.87	95	932	10.50			20.59	2.01
	f										
11	s		1.779	0.88	95	855	11.50			22.54	2.02
	f										
12	s		1.771	0.88	95	708	12.80			25.10	1.86
	f										
13	s		1.781	0.87	95	548	13.00			25.48	1.46
	f										
14	s		1.761	0.87	97	455	13.15			25.77	1.23
	f										
15	s		1.770	0.87	97	360	13.20			25.87	.97
	f										
16	s		1.775	0.87	97	249	13.30			26.07	.68
	f										
17	s		1.778	0.87	97	156	14.15			27.73	.45
	f										

COMMENTS: _____

T			rpm			D
29.50	1.762	.081	104	15.05	97°	.32
30.19	1.773	.087	57	15.40	97	.09
30.13	1.788	.087				
	1.768	.087	0	4.15	98	(0° pos on tunnel
	1.768	.087	0	21.5?	"	(blade ½ way)
			2496	0	100°	(540 on dummy)

~~2496~~ ~~540 in tunnel~~

Position tried after making initial stall test - slippage first suspected.

Test No. ←

Date 2 May

TTU-NASA WWT TEST DATA

Performance Test of Model _____ WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) _____ T_{room} 72 °F; P_{Bar} 29.13 "Hg; T_{Bar} 24.8 °C

Re for 0500 - 6425 78 29.14 25.3

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.552	1.30	80	3004	0			0	0
	f										
2	s		2.542	1.30	86	2824	1.50			2.94	0.87
	f										
3	s		2.537	1.30	92	2624	3.20			6.30	1.66
	f										
4	s		2.519	1.30	90	2317	4.75			9.31	2.45
	f										
5	s		2.530	1.30	90	2522	4.45			8.72	2.30
	f										
6	s		2.509	1.30	92	2382	6.30			12.34	3.05
	f										
7	s		2.517	1.28	92	2275	7.45			14.60	3.48
	f										
8	s		2.516	1.27	93	2154	8.65			16.95	3.82
	f										
9	s		2.512	1.28	93	2002	10.20			19.99	4.19
	f										
10	s		2.485	1.27	95	1854	11.50			22.54	4.37
	f										
11	s		2.501	1.27	95	1742	11.10			21.75	3.97
	f										
12	s		2.500	1.26	98	1610	11.45			22.44	3.78
	f										
13	s		2.501	1.26	98	1505	11.50			22.54 ~~20.48~~	3.55
	f										
14	s		2.496	1.27	98	1348	13.00			25.48	3.60
	f										
15	s		2.495	1.26	99	1216	14.25			27.93	3.55
	f										
16	s		2.497	1.27	99	1053	15.90			31.16	3.44
	f										
17	s		2.487	1.27	99	918	17.00			33.32	3.20
	f										

COMMENTS: _____

Vel.	Sp.	T.	rpm	gr.	T	P
2.477	1.27	102°	750	18.20	35.67	2.80
2.487	1.26	100°	604	18.45	36.16	2.29
2.483	1.26	100	506	18.75	36.75	1.95
2.482	1.26	100	349	19.70	38.61	1.41
2.482	1.26	100	212	21.20	41.55	0.92
2.480	1.26	101	110	22.10	43.31	0.50
2.475	1.27	101	55	22.30	43.70	0.25
2.475	1.27	101	0	6.2	12.15 gr — 0 pos on drawing can't get inbetween - it locks over to 0	0
2.471	1.28	107	2985	0		

10:30 Am Complete

Test No. 5
Date 3 March '81

TTU-NASA WWT TEST DATA

Performance Test of Model _____ WWT, Config. ______________________

Test Objective ______________________

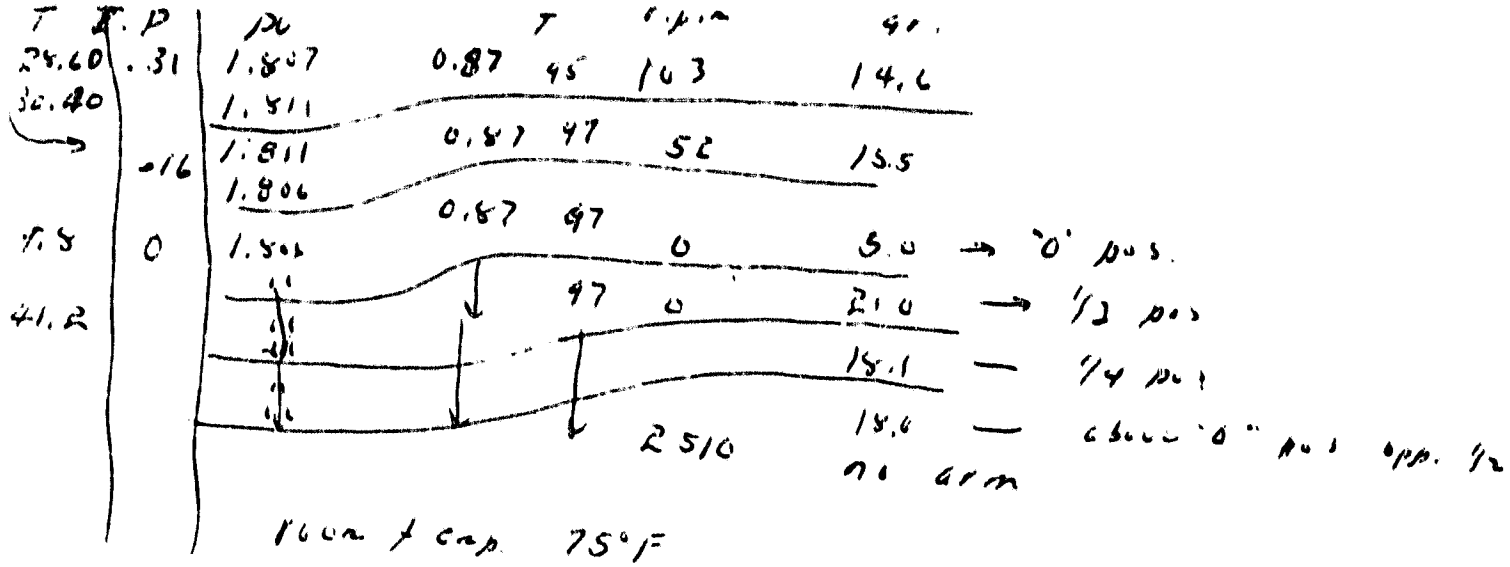
Test Cond. ______________________

Observer(s) M. A. Pucci T_{room} 72 / 75 °F; P_{Bar} 29.26 / 29.22 "Hg; T_{Bar} 24.3 / 24.8 °C

Dwyer: 5500 - 5500

Data Pt. No.		Time (warm up 15 min)	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	m/s	Torque T mN·m	Power P Watts
1	s	9:45	1.847	0.90	[illegible]	2564	0	5586	28.37	0	0
	f		1.847	0.90	85						
2	s		1.826	0.90	86	~~2286~~	2.15	5564	28.27	4.21	1.03
	f		1.832			2345					
3	s		1.832	0.90	88	2200	3.00	5590	28.40	5.88	1.35
	f		1.817								
4	s		1.817	0.90	88	2004	4.80	5556	28.28	9.41	1.97
	f										
5	s		1.839	0.90	89	1810	6.20	5595	28.42	12.15	2.30
	f										
6	s		1.830	0.90	90	1643	7.90	5574	28.32	15.48	2.66
	f		1.814								
7	s		1.832	0.90	90	1410	8.10	5580	28.35	15.87	2.34
	f		1.829								
8	s		1.823	0.90	92	1285	8.20	5583	28.37	16.10	2.17
	f		1.819								
9	s		1.812	0.90	92	1138	9.25	5568	28.30	18.13	2.16
	f		1.812								
10	s		1.812	0.90	92	950	10.50	5568	28.30	20.60	2.05
	f		1.812								
11	s		1.812	0.90	93	828	12.00	5575	28.33	23.52	2.04
	f		1.811								
12	s		1.811	0.90	93	700	13.00	5574	28.32	25.50	1.87
	f		1.811								
13	s		1.811	0.90	93	547	13.35	5577	28.34	26.20	1.50
	f		1.811								
14	s		1.811	0.87	95	458	13.35	5580	28.36	26.20	1.28
	f		1.806								
15	s		1.866	0.87	95	347	13.70	5579	28.35	26.85	0.98
	f		1.806								
16	s		1.806	0.87	95	242	13.80	5576	28.33	27.05	0.68
	f		1.802								
17	s		1.807	0.87	95	149	14.50	5582	28.31	28.42	0.44
	f		1.812								

COMMENTS: ______________________



Room temp. 75°F

Test ended 11:05

Data Point	V_w Ft./min	V_w m/s
18	5582	28.37
19	5544	28.42
20	5584	28.40

Test No. 0

TTU-NASA WWT TEST DATA

Nom. Wind Vel. 650 - 680

Date 4 March 83

Performance Test of Model ____ WWT, Config. ____

Test Objective ____

Test Cond. ____

Observer(s) B. L Cook T_{room} 72 °F; P_{Bar} 28.94 "Hg; T_{Bar} 24.2 °C

Day ~~650 - 680~~ time start 8:35 end 10:10

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	8:35	2.55	1.30	85	3012	0			0	0
	f		2.55								
2	s		2.542	1.30	88	2755	2.5	6611	33.59	4.90	1.41
	f		2.552								
3	s		2.534	1.30	88	2617	4.25			8.33	2.28
	f		2.545								
4	s		2.542	1.30	91	2450	5.80	6623	33.66	11.37	2.92
	f										
5	s		2.523	1.30	91	2312	7.40			14.50	3.51
	f		2.529								
6	s		2.533	1.30	93	2150	9.20			18.03	4.06
	f		2.518								
7	s		2.508	1.30	93	2001	10.80	6586	33.47	21.17	4.43
	f		2.503								
8	s		2.520	1.30	93	1804	11.60			22.74	4.30
	f		2.525								
9	s		2.512	1.28	97	1708	11.45			22.40 ~~22.90~~	4.00
	f		2.512								
10	s		2.512	1.29	97	1501	11.60	6609	33.56	22.73	3.57
	f		2.504								
11	s		2.506	1.28	97	1402	12.40			24.30	3.57
	f		2.506								
12	s		2.506	1.28	97	1250	14.10	6597	33.53	27.64	3.62
	f		2.500								
13	s		2.506	1.28	100	1104	15.40			30.20	3.49
	f		2.498								
14	s		2.506	1.28	100	947	16.90	6608	33.56	33.12	3.28
	f		2.492								
15	s		2.498	1.28	100	853	18.00 ~~18.80~~			35.30	3.15
	f		2.497								
16	s		2.497	1.28	100	706	18.70			36.70	2.71
	f		2.497								
17	s		2.499	1.28	100	559	19.10	6609	33.56	37.44	2.19
	f		2.494								

COMMENTS: ____

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		2.494	1.28	102	440	19.50			38.22	1.76
	f		2.501								
19	s		2.496	1.28	102	339	20.01			39.20	1.39
	f		2.493								
20	s		2.493	1.28	102	203	21.70			42.53	0.90
	f		2.493								
21	s		2.487	1.28	102	105	22.30			43.71	0.48
	f		2.485								
22	s		2.495	1.28	102	53	22.60			44.30	0.25
	f		2.496								
23	s		2.490	1.28	102	0	7.20			14.11	0
	f										
24	s			1.28	102	0	32.0			62.72	0
	f										
25	s	10:10	2.496	1.28	102	~~2997~~	25.7			50.37	0
	f										
26	s		2.496	1.28	102	2997	0			0	
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 77 °F, P_{Bar} 28.91 "H_2O, T_{Bar} 24.2 °C, Time 18:10

COMMENTS: _____

Test No. 7

Nom. Wind Vel. 5500 FPM

Date 5 May 8

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. S/A - As per Drawing

Test Objective

Test Cond.

Observer(s) [illegible] T_{room} 74 °F; P_{Bar} 29.11 "Hg; T_{Bar} 22.5 °C

time start 12:30 end 1:33

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	12.30	1.824	.94	82	2424	No Load			0	0
	f		1.844								
2	s		1.824	.94	90	2221	0.8			5.65	1.31
	f										
3	s		1.816	.94	90	2019	1.4			9.88	2.09
	f										
4	s		1.812	.94	90	1813	1.8			12.71	2.41
	f										
5	s		1.812	.94	90	1701	2.3			16.24	2.89
	f										
6	s		1.809	.94	90	1610	2.3			16.24	2.74
	f										
7	s		1.809	.93	93	1483	2.6			18.36	2.85
	f										
8	s		1.807	.93	93	1395	2.3			16.24	2.37
	f										
9	s		1.802	.91	93	1297	2.4			16.95	2.30
	f										
10	s		1.802	.91	93	1180	2.6			18.36	2.27
	f										
11	s		1.802	.91	93	1074	2.8			19.77	2.22
	f										
12	s		1.802	.91	94	1001	3.0			21.18	2.22
	f										
13	s		1.797	.91	94	896	3.2			22.45	2.11
	f										
14	s		1.797	.91	95	797	3.6			25.41	2.12
	f										
15	s		1.797	.91	95	693	3.8			26.83	1.95
	f										
16	s		1.797	.91	95	623	3.8			26.83	1.75
	f										
17	s		1.797	.91	95	502	3.8			26.83	1.41
	f										

COMMENTS: No Load is mechanical friction of motor/gen only, brushes UP

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H$_2$O	Static Press P_s "H$_2$O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) oz/in	Velocity V_w fpm	m/s	Torque T mN·m	Power P Watts
18	s		1.797	.91	95	400	4.1			28.95	1.21
	f										
19	s		1.797	.91	95	349	4.7			33.18	1.21
	f										
20	s	1.33	1.797	.91	95	246	4.8			33.89	.87
	f										
21	s						Stall *				
	f										
22	s					2428	No Load				
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 77 °F, P_{Bar} 29.67 "Hg, T_{Bar} 23.0 °C, Time 1.33

COMMENTS: * 1.8 - - 0.5 - 2.1 - 3.1 oz-in Some variation when wheel was indexed

TTU-NASA WWT TEST DATA

Test No. 8.0
Nom. Wind Vel. 65.00 F/m
Date 5 May 81

Performance Test of Model A WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) M. A. Cuevas T_{room} 78 °F; P_{Bar} 29.06 "Hg; T_{Bar} 23.0 °C
time start 2:45 end 3:57

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	2:45	2.593	.33	85	2938	No Load			0	0
	f										
2	s		2.590	.35	85	2502	1.9			13.41	3.51
	f										
3	s		2.591	35	95	~~2012~~ 2129	2.8			19.77	4.41
	f										
4	s		2.593	.35	93	1894	3.7			26.12	5.18
	f										
5	s		2.593	.35	95	1772	~~3.4~~ 3.5			24.71	4.58
	f										
6	s		2.577	.35	95	1612	3.4			24.00	4.05
	f										
7	s		2.557	.35	98	1497	3.6			25.41	3.98
	f										
8	s		~~2.576~~	.35	100	1396	3.5			24.71	3.61
	f										
9	s		2.573	.35	100	1291	4.0			28.24	3.82
	f										
10	s		2.573	.35	100	1201	4.2			29.65	3.72
	f										
11	s		2.559	.35	100	1084	4.6			32.48	3.68
	f										
12	s		2.559	.35	100	986	4.9			34.60	3.57
	f										
13	s		2.562	.35	100	898	5.4			38.13	3.58
	f										
14	s		2.560	.35	100	800	5.2			36.72	3.07
	f										
15	s		2.554	.35	100	725	5.8			40.95	3.11
	f										
16	s		2.554	.35	100	594	5.7			40.24	2.50
	f										
17	s		2.554	.35	103	499	6.2			43.78	2.29
	f										

COMMENTS: No Load is mechanical friction of motor/gen. only

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		2.568	.35	103	400	6.4			45.19	1.89
	f										
19	s		2.556	.35	103	303	6.6			46.60	1.48
	f										
20	s		2.556	.35	103	195	7.2			50.84	1.04
	f										
21	s						Stall * 5.35			37.78	6
	f										
22	s					2986	No Load			~~37.78~~	
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} AO °F, P_{Bar} 29.04 "Hg "H_2O, T_{Bar} 23.5 °C, Time 3:57

COMMENTS: * 5.1 - 4.3 - 2.6 - 5.3 - 6.7 - 3.3 - 9.7 oz/in Stall range - Ave.

Test No. 4
Nom. Wind Vel. 6500
Date 7 May '91

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. 5 ft. - As per Drawing

Test Objective

Test Cond.

Observer(s) M. A. Ruder T_{room} 76 °F; P_{Bar} 29.69 "Hg; T_{Bar} 19.5 °C

time start 9:15 end 9:35

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H₂O	Static Press P_S "H₂O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ oz/in	Velocity V_w fpm	m/s	Torque T mN·m	Power P Watts
1	s		2.588	.33	84	3053	0			0	0
	f										
2	s		2.588	.33	84	2570	1.2			8.47	2.30
	f										
3	s		2.556	.33	84	2062	2.8			19.77	4.31
	f										
4	s		2.572	.33	87	1852	3.4			24.00	4.68
	f										
5	s		2.561	.33	87	1733	3.1			21.89	3.97
	f										
6	s		2.565	.33	88	1615	3.3			23.30	3.94
	f										
7	s		2.563	.33	88	1497	3.2			22.54	3.54
	f										
8	s		2.560	.33	88	1404	3.7			26.12	3.85
	f										
9	s		2.555	.33	91	1305	3.9			27.54	3.76
	f										
10	s		2.552	.33	91	1203	4.3			30.36	3.82
	f										
11	s		2.547	.30	91	1052	4.6			32.48	3.71
	f										
12	s		2.541	.30	92	996	4.6			32.48	3.39
	f										
13	s		2.541	.31	92	897	5.0			35.30	3.32
	f										
14	s		2.541	.31	92	804	5.5			38.84	3.27
	f										
15	s		2.541	.30	92	701	5.3			37.42	2.75
	f										
16	s		2.541	.31	92	599	5.2			36.72	2.30
	f										
17	s		2.541	.32	93	502	5.7			40.25	2.12
	f										

until readout shows "0" torque.

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H$_2$O	Static Press P_s "H$_2$O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		2.541	.31	93	311	6.5			45.90	1.92
	f										
19	s		2.541	.31	93	312	6.5			49.01	1.57
	f										
20	s		2.571	.31	93	203	7.0			49.43	1.05
	f										
21	s						Stall				
	f										
22	s					3068	No Load				
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 73 °F, P_{Bar} 29.09 "H_2O, T_{Bar} 19.5 °C, Time 9:35

COMMENTS:

Test No. 10
Nom. Wind Vel. 5500
Date 7 May 8.

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. STD - As per Drawing

Test Objective Torque-Speed Curve.

Test Cond.

Observer(s) Collicott, Kaufman, Smith T_{room} 71.5 °F; P_{Bar} 29.09 "Hg; T_{Bar} 19.0 °C

time start 1:35 end 2:17

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ oz / in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s	1:31	1.820	.90	78	2584	~~2584~~ 0			0	0
	f										
2	s		1.790	.90	78	2209	0.90			6.35	1.47
	f										
3	s		1.807	.92	81	2029	1.4			9.89	2.10
	f										
4	s		1.799	.92	81	1811	1.8			12.71	2.41
	f										
5	s		1.797	.91	83	1707	2.2			15.53	2.78
	f										
6	s		1.797	.91	83	1605	2.1			14.83	2.49
	f										
7	s		1.793	.91	83	1400	2.3			16.24	2.30
	f										
8	s		1.790	.90	83	1298	2.5			17.65	2.40
	f										
9	s		1.790	.90	83	1212	2.6			18.36	2.33
	f										
10	s		1.787	.90	83	1095	2.8			19.77	2.27
	f										
11	s		1.787	.90	86	993	3.0			~~21.60~~ 19 21.19	2.20
	f										
12	s		1.787	.90	86	904	3.3			23.30	2.21
	f										
13	s		1.787	.90	86	803	3.3			23.30	1.91
	f										
14	s		1.787	.90	86	703	3.9			27.54	2.03
	f										
15	s		1.787	.90	86	602	4.1			28.95	1.82
	f										
16	s		1.787	.90	86	~~494~~ 486	~~4.~~ 3.9			27.54	1.40
	f										
17	s		1.787	.90	86	392	4.4			31.07	1.28
	f										

COMMENTS: No load obtained same as in Test 9 7 May. Motor heat

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H$_2$O	Static Press P_s "H$_2$O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ OZ/Fin gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s		1.787	.90	86	297	5.5			38.84	1.21
	f										
19	s		1.783	.90	86	196	5.0			35.31	0.72
	f										
20	s					0	Stall				
	f										
21	s		0° pos of blade:								
	f										
22	s		5.2 - 0.6 - 3.5			2.45					
	f		0.8 - 2.5 - 2.1								
23	s		1/2 pos of blade								
	f										
24	s		6.0 - 6.4 - 7.3			6.56					
	f		6.2 - 6.8 - 6.7								
25	s		1/4 pos of blade								
	f										
26	s		6.0 - 6.2 - 5.4			5.88					
	f		5.4 - 6.3 - 6.0								
27	s		3/4 pos of blade								
	f										
28	s		5.3 - 5.6 - 6.2			5.6	5.12 avg.			36.17	
	f		5.7 - 5.7 - 5.1								
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 72.0 °F, P_{Bar} 29.9 "Hg, T_{Bar} 18.0 °C, Time ~~7:30~~ 2:17

COMMENTS: _____

Test No. 11 ⊗
Nom. Wind Vel. 7000 fpm
Date 7 May

TTU-NASA WWT TEST DATA

Performance Test of Model A WWT, Config. Std. as per Drawing

Test Objective

Test Cond.

Observer(s) Kaufman - Collick T_{room} °F; P_{Bar} "Hg; T_{Bar} °C

time start 3:30 end 3:45 $P_{Bar_{corr}}$ "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	~~Force~~ (Torque) ~~Arm~~ oz/in sm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		—	—	85	3277	0			0	0
	f										
2	s					3069	1.0			7.1	2.24
	f										
3	s					2734	1.8			12.71	3.64
	f										
4	s					2197	3.4			24.00	5.52
	f										
5	s					1733	3.8			26.83	4.87
	f										
6	s					1297	5.0			35.31	4.79
	f										
7	s					1192	5.1			36.01	4.49
	f										
8	s					928	5.9			41.66	4.04
	f										
9	s					704	6.3			44.48	3.28
	f										
10	s					412	7.6			55.05	2.37
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: ⊗ Survey Test - Not intended to be Complete
Motor boost r.p.m. until readout gave "0" torque

Test No. 11-1

Nom. Wind Vel. 55 00

Date 12 May

TTU-NASA WWT TEST DATA

Performance Test of Model K WWT, Config. Alum. Model by NASA

Test Objective

Test Cond.

Observer(s) M. A. Collier T_{room} 65 °F; P_{Bar} 29.24 "Hg; T_{Bar} 15.5 °C

time start 1:16 end 1:35 $P_{Bar\,corr}$ same "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.833	.83	76	2063	0			0	0
	f										
2	s		1.824	.83	78	1871	2.7			19.06	3.73
	f										
3	s		1.815	.83	78	1655	5.2			36.7	6.36
	f										
4	s		1.815	.83	78	1464	7.4			52.25	8.00
	f										
5	s		1.806	.83	78	1357	8.6			60.72	8.64
	f										
6	s		1.806	.83	82	1263	9.7			68.49	9.05
	f										
7	s		1.806	.83	.82	1178	10.8			76.26	9.40
	f										
8	s										
	f										
9	s										
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Too much load for generator - overheats in Buck pos.

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} ____ °F, P_{Bar} 29.24 "Hg, T_{Bar} 15.5 °C, Time 1:35

COMMENTS: _____

Test No. K-2
Nom. Wind Vel. 4700
Date 13 May 81

TTU-NASA WWT TEST DATA

Performance Test of Model H WWT, Config. Alum. Model by NASA

Test Objective

Test Cond.

Observer(s) M. A. Cocus T_{room} 63 °F; P_{Bar} 29.20 "Hg; T_{Bar} 17.0 °C
time start 9:15 end 9:31 $P_{Bar_{corr}}$ None "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.316	.58	73	1746	0			0	0
	f										
2	s		1.316	.58	73	1544	2.3			16.24	2.63
	f										
3	s		1.316	.59	77	1344	4.3			30.36	4.27
	f										
4	s		1.316	.58	77	1144	6.6			46.60	5.58
	f										
5	s		1.316	.58	77	1042	7.1			50.13	5.47
	f										
6	s		1.316	.58	77	944	8.3			58.60	5.79
	f										
7	s		1.310	.58	77	840	9.1			64.25	5.65
	f										
8	s		1.310	.58	78	743	10.1			71.30	5.55
	f										
9	s		1.310	.59	78	642	10.3			72.72	4.89
	f										
10	s		1.310	58	78	546	11.7			82.61	4.72
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Too much load for for motor. Cannot Buck lower than 575 r.p.m. Use Penny Brake for load

Nom. Wind Vel. 4700 fpm
Date 13 May

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) In-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 64 °F, P_{Bar} 29.2 "Hg, T_{Bar} ~~22.2~~ 17.0 °C, Time 9:31

COMMENTS:

Test No. A-3
Nom. Wind Vel. 55.00
Date 13 May 82

TTU-NASA WWT TEST DATA

Performance Test of Model K WWT, Config. Alum. Model by NASA

Test Objective

Test Cond.

Observer(s) M. A. Galvez T_{room} 67 °F; P_{Bar} 29.17 "Hg; T_{Bar} 18.0 °C

time start 2:24 end 2:43 $P_{Bar\,corr}$ -.05 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.811	.82	74	2015*	—			?	
	f		1.827	.83	76	2016	—				
2	s		1.811	.82	74	1935**	3.0			19.77	~~3.87~~ 3.87
	f		1.820	.82	80	1810	2.8				
3	s		1.803	.82	74	1631	5.3			37.42	6.53
	f		1.818	.82	85	1667	5.3				
4	s		1.791	.82	80	1430	7.7			53.66	8.23
	f		1.812	.82	85	1465	7.6				
5	s		1.791	.82	90	1236	9.7			69.20	9.23
	f		1.818	82	85	1275	9.8				
6	s		1.791	.82	80	1037	12.2			84.73	9.56
	f		1.811	82	85	1078	12.6				
7	s		1.791	.82	83	835	14.2			102.38	9.34
	f		1.811	.83	85	871	14.5				
8	s		1.791	.82	83	634	15.8			113.0	7.97
	f		1.811	.82	85	674	16.0				
9	s		1.791	.80	83	438	17.6			125.68	6.18
	f		1.811	.82	88	470	17.8				
10	s									134.16	5.32
	f		1.777	.82	88	379	19.0				
11	s									137.00	3.96
	f		1.779	.82	88	276	19.4				
12	s					126	19.8			139.80	2.58
	f		1.813	.82	88	~~126~~	~~19.7~~				
13	s									77.67	
	f		1.813	.82	88	0	11.0				
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

Rubber coupler slipping after this load

COMMENTS: * Brushes UP - Tares, friction and Pony Brake drag

** Brushes Down. Shaft coupling friction improved so that a stall was obtained but only at one blade position.

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 69 °F, P_{Bar} 29.12 "Hg, T_{Bar} 18.5 °C, Time 2143

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-4
Nom. Wind Vel. 6500
Date 14 May 8

Performance Test of Model K WWT, Config. Alum. Model by NASA
Test Objective
Test Cond.
Observer(s) M. A. Cecil T_{room} 67 °F; P_{Bar} 28.93 "Hg; T_{Bar} 20.0 °C
time start 10:50 end 11:25 $P_{Bar\,corr}$ - "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.532	1.15	73	2400	—			0	0
	f										
2	s		2528	1.15	73	2252	3.0	6499		21.20	4.99
	f										
3	s		2.519	1.15	80	2056	5.9	6529		41.65	8.96
	f										
4	s		2.512	1.15	80	1857	8.3	6520		58.60	11.40
	f										
5	s					~~1640~~	~~10~~	6544		81.20	14.05
	f		2.512	1.15	64	1653	11.5				
6	s		2.499	1.15	84	1453	13.7	6528		96.73	14.07
	f										
7	s		2.499	1.15	84	1251	16.0	6528		112.97	14.79
	f										
8	s		2.492	1.15	85	1046	18.4	6525		129.92	14.23
	f										
9	s		2.484	1.15	85	854	19.8	6514		139.80	12.57
	f										
10	s		2.484	1.15	95	647	21.9	6514		154.63	10.47
	f										
11	s		2.484	1.15	88	453	23.6	6532		166.63	7.90
	f										
12	s		2.484	1.15	88	245	24.7	6532		174.41	4.47
	f										
13	s					~~156~~	~~24.8~~	6532		178.64	2.80
	f		2.484	1.15	88	150	25.3				
14	s					0 ⑧	16.3			115.09	0
	f	18.1 - 16.9 - 14.4 - 15.2 - 17.1 →					Ave.				
15	s	⑧ The following applies to the stall test only.									
	f										
16	s	Bar. - 28.96 Hg.				Tun. temp. - 88°F					
	f	T_{dp} - 19°C				Stat. Press - 1.18					
17	s	Room - 68°F				Mon. - 2.570					
	f	No Load r.p.m - 2434									

COMMENTS: No load (—) is brushes UP. Transducer & Torque Arm only load. Slippage does not permit checking torque in various blade positions. Stalling occurs only in the minimum loadi

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v $''H_2O$	Static Press P_s $''H_2O$	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 64 °F, P_{Bar} 28.91 "Hg, T_{Bar} 20.5 °C, Time N.25

COMMENTS: torque position of blade

Test No. 17-5

TTU-NASA WWT TEST DATA

Nom. Wind Vel. 4000

Date 22 May

Performance Test of Model K WWT, Config. _____

Test Objective Find Stall Torque at various blade positions

Test Cond. _____

Observer(s) M.A. Clark T_{room} 66 °F; P_{Bar} 29.25 "Hg; T_{Bar} 19.5 °C

time start 8:45 end 9:00 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) ~~Arm~~ OZ / ~~gm~~	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		0.473	.40	80	0	↓			0	0
	f										
2	s		Normal Stall: 5.6 - 5.6				↓				
	f										
3	s		5.9 - 7.4 - 6.4 - 6.9 - 7.1				6.57			46.39	
	f		7.5 = 6.57 Avg →								
4	s		Blade pos. (0): 5.3								
	f		3.7 - 4.1 - 3.0 - 4.3 - 3.7								
5	s		5.1 = 3.98 Avg. →				3.98			28.10	
	f										
6	s		Blade pos 14: 12.1 - 11.8				12.83			90.59	
	f		11.9 - 14.6 - 13.8 - 12.8 →								
7	s		Blade pos. 12: 15.5 - 16.3				15.32			108.17	
	f		14.1 - 16.6 - 15.2 - 14.2 →								
8	s										
	f										
9	s										
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: No Load r.p.m. - 1478 (bearings & torque arm only load)

Nom. Wind Vel. _____ fpm

TTU NASA WWT TEST DATA (continued)

Date _____

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H$_2$O	Static Press P_S "H$_2$O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 73 66 °F, P_{Bar} 29.25 "H$_2$O, T_{Bar} 19.5 °C, Time 9:00

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-6
Nom. Wind Vel. 6500
Date 22 May

Performance Test of Model K-3 WWT, Config. ____

Test Objective To determine if stall conditions change Speed/Power

Test Cond. ratio curve. Refer to K-3 test

Observer(s) T.A. Ciesk T_{room} 67 °F; P_{Bar} 29.25 "Hg; T_{Bar} 19.5 °C

time start 9:15 end 9:48 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s	...	2.587	1.18	83	2430	No Load			0	0
	f										
2	s		2.587	1.18	83	2281	2.9			20.47	4.89
	f										
3	s		2.563	1.18	83	2081	6.3			44.48	9.69
	f										
4	s		2.580	1.18	85	1880	8.5			60.02	11.81
	f										
5	s		2.580	1.18	87	1680	11.3			79.79	14.03
	f										
6	s		2.558	1.18	87	1480	13.7			96.73	14.99
	f										
7	s	...	2.562	1.18	87	1280	17.1			120.7	16.17
	f										
8	s		2.553	1.18	87	1083	19.3			136.3	15.45
	f										
9	s		2.553	1.18	90	985	21.8			153.9	14.26
	f										
10	s		2.553	1.18	90	680	23.1			163.1	11.61
	f										
11	s		2.553	1.18	90	484	24.6			173.7	8.80
	f										
12	s		2.553	1.18	92	283	25.6			180.7	5.35
	f										
13	s		2.553	1.18	92	180	26.8			189.2	3.56
	f					179	>				
14	s		2.553	1.18	92	119	26.5			187.1	2.33
	f										
15	s		2.553	1.18	92	107	27.5			194.2	2.17
	f										
16	s	some slippin				0					
	f										
17	s										
	f										

COMMENTS: It is possible the normal stall was not obtained (vs K-3 test) due to the higher temperature in Lab.

This test taped all coupling joints in addition to having the

TTU-NASA WWT TEST DATA

Test No. K-7
Nom. Wind Vel. 7000 ft
Date 22 May '82

Performance Test of Model K-3 WWT, Config. _____

Test Objective _____

Test Cond. _____

Observer(s) M.A. Ebert T_{room} 70 °F; P_{Bar} 29.25 "Hg; T_{Bar} 21.0 °C
time start 11:45 end 12:05 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) ~~Nm~~ oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.946	.38	78	2582	No Load				
	f										
2	s		2.946	.38	78	2450	3.0			21.18	5.43
	f										
3	s		2.946	.38	85	2246	6.5			45.89	10.79
	f										
4	s		2.936	.38	85	2043	9.8			69.20	14.80
	f										
5	s		2.936	.38	87	1832	12.5			88.26	16.92
	f										
6	s		2.936	.38	87	1644	15.1			106.6	18.35
	f										
7	s		2.922	.38	87	1448	18.2			128.5	19.48
	f										
8	s		2.922	.38	87	1243	20.6			145.5	18.93
	f										
9	s					2605	No Load				
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: *Survey Test Not intended to be Complete

TTU-NASA WWT TEST DATA

Test No. K-5
Nom. Wind Vel. 5500 fpm
Date 19 June 81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Wing ports open. Front port and top of wheel blocked

Observer(s) W. A. Cecil T_{room} 83 °F; P_{Bar} 29.17 "Hg; T_{Bar} 28.0 °C

time start 1:30 end 1:55 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in g	Velocity V_W fpm	Velocity V_W m/s	Torque T mN·m	Power P Watts
1	s		1.817	.87	87	1528	No load			0.7	0
	f										
2	s		1.817	.87	92	1232	2.9			20.47	2.64
	f										
3	s		1.817	.87	92	1033	4.9			35.60	3.85
	f										
4	s		1.817	.87	92	835	7.1			50.13	4.38
	f										
5	s		1.817	.87	94	634	7.9			55.78	3.70
	f										
6	s		1.817	.87	94	434	9.7			68.50	3.11
	f										
7	s		1.817	.87	94	339	9.1			64.25	2.28
	f										
8	s		1.817	.87	94	239	11.3			79.80	2.00
	f										
9	s		1.817	.85	95	~~136~~ 139	~~11.3~~ 10.5			74.14	1.08
	f										
10	s		1.798	.85	95	77	9.8			69.20	0.56
	f										
11	s		1.798	.85	95	0	5.9			41.66	0
	f										
12	s		1.795	.85	95	1527	No load				
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Only one stall point possible - slippage occuring at intermediate points. "No Load" is transducer with brushes raised plus torque arm

Nom. Wind V. 5500 fpm

Date 19 Nov 91

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 83 °F, P_{Bar} 29.16 "H_2O, T_{Bar} 29.6 °C, Time 1:55

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-9
Nom. Wind Vel. 6500 fpm
Date 19 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-8

Test Cond. Same as K-8 (except wind vel.)

Observer(s) M. A. Collier T_{room} 84 °F; P_{Bar} 29.16 "Hg; T_{Bar} 25.0 °C

time start 2:50 end 3:13 $P_{Bar_{corr}}$ _____ "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.604	1.25	93	1859	No load			0	0
	f										
2	s		2.570	1.25	93	1607	3.3			23.30	3.92
	f										
3	s		2.565	1.25	95	1407	5.1			36.00	5.30
	f										
4	s		2.565	1.25	95	1202	7.2			50.84	6.35
	f										
5	s		2.565	1.25	98	1005	9.2			65.00	6.84
	f										
6	s		2.565	1.25	98	908	10.3			72.72	6.91
	f										
7	s		2.565	1.25	98	802	11.4			80.50	6.76
	f										
8	s		2.565	1.25	100	708	12.3			86.85	6.44
	f										
9	s		2.565	1.23	100	607	13.6			91.80	5.83
	f										
10	s		2.565	1.23	100	507	13.7			96.73	5.13
	f										
11	s		2.565	1.23	100	408	13.5			95.32	4.07
	f										
12	s		2.565	1.23	100	309	14.4			101.70	3.29
	f										
13	s		2.560	1.20	102	208	15.0			105.90	2.31
	f										
14	s		2.529	1.20	102	109	14.1			99.56	1.14
	f										
15	s		2.529	120	104	0	8.7			61.43	0
	f										
16	s		2.529	1.20	104	1842	No Load				
	f										
17	s										
	f										

COMMENTS: Only one stall point possible - slippage occuring at intermediate points. "No Load" is transducer with brushes raised + torque arm

Test No. _____ pg

Nom[illegible] Ind Vel. _____ fpm

Date _____

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V $"H_2O$	Static Press P_S $"H_2O$	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85 °F, P_{Bar} 29.16 $"H_2O$, T_{Bar} 29.0 °C, Time 3:13

COMMENTS: _____

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TTU-NASA WWT TEST DATA

Test No. K-16
Nom. Wind Vel. 5500 fpm
Date 22 June 81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Wheel Open - Front Port and Wings Blocked

Observer(s) M. A. Cobil T_{room} 83 °F; P_{Bar} 29.12 "Hg; T_{Bar} 28.5 °C

time start 10:50 end 11:15 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.822	.85	84	1542	No Load			0	0
	f										
2	s		1.822	.85	87	1266	3.1			21.89	2.90
	f										
3	s		1.789	.85	81	1054	4.8			33.90	3.74
	f										
4	s		1.788	.85	90	965	6.7			47.30	4.28
	f										
5	s		1.808	.85	90	668	7.6			53.66	3.75
	f										
6	s		1.769	.85	92	565	7.6			53.66	3.17
	f										
7	s		1.780	.84	92	460	8.2			57.90	2.79
	f										
8	s		1.773	.84	92	361	7.9			55.78	2.11
	f										
9	s		1.774	.84	94	261	8.4			59.31	1.62
	f										
10	s		1.774	.84	94	166	9.3			65.67	1.14
	f										
11	s		1.802	.84	94	103	9.1			64.25	0.69
	f										
12	s		1.802	.84	94	0	6.4			45.20	0
	f										
13	s		1.802	.84	95	1543	No Load				
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Only one stall point possible - Slippage occuring at intermediate points. "No Load" is transducer with brushes raised plus torque arm.

Test No. A-10 pg
Nom Wind Vel. 5500 fpm
Date 22 June '87

TTU NASA WWT TEST DATA (continued)

Data Pt. No.	Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18 s/f										
19 s/f										
20 s/f										
21 s/f										
22 s/f										
23 s/f										
24 s/f										
25 s/f										
26 s/f										
27 s/f										
28 s/f										
29 s/f										
30 s/f										
31 s/f										
32 s/f										
33 s/f										
34 s/f										

Final Room Data: T_{room} 84 °F, P_{Bar} 29.12 "H_2O, T_{Bar} 28.5 °C, Time _____

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-11

Nom. Wind Vel. 6500 fpm

Date 22 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-10

Test Cond. Same as K-10 (except wind vel.)

Observer(s) M. A. Collier T_{room} 84 °F; P_{Bar} 29.13 "Hg; T_{Bar} 28.5 °C

time start 12:05 end 12:25 $P_{Bar\,corr}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_W fpm	Velocity V_W m/s	Torque T mN·m	Power P Watts
1	s		2.603	1.23	87	1890	No Load			0	0
	f										
2	s		2.603	1.23	88	1664	3.0			21.19	3.69
	f										
3	s		2.603	1.23	95	1462	5.2			36.71	5.54
	f										
4	s		2.603	1.23	95	1261	7.3			51.54	6.80
	f										
5	s		2.603	1.23	95	1063	9.8			69.20	7.70
	f										
6	s		2.551	1.23	98	968	10.3			72.73	7.37
	f										
7	s		2.556	1.23	98	864	10.8			76.26	6.90
	f										
8	s		2.556	1.23	98	769	11.1			78.38	6.31
	f										
9	s		2.556	1.23	100	664	11.1			78.38	5.45
	f										
10	s		2.556	1.23	100	566	10.9			76.96	4.56
	f										
11	s		2.556	1.23	100	464	10.8			76.26	3.70
	f										
12	s		2.556	1.23	100	366	11.7			82.61	3.16
	f										
13	s		2.556	1.23	100	262	12.7			89.67	2.46
	f										
14	s		2.556	1.23	103	169	13.8			97.44	1.72
	f										
15	s		2.538	1.23	103	102	13.2			93.20	0.99
	f										
16	s		2.539	1.23	103	6	10.8			76.26	0
	f										
17	s		2.538	1.23	103	1888	No Load				
	f										

COMMENTS: _____

Test No. A-11 p
No[illegible], Wind Vel. 6500 fpm
Date 22 Mar '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
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24	s										
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27	s										
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28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85 °F, P_{Bar} 29.13 "H_2O, T_{Bar} 26.5 °C, Time 12:25

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-12
Nom. Wind Vel. 5500 fpm
Date 22 June '91

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Front port and wheel open - wings blocked

Observer(s) _____ T_{room} 85 °F; P_{Bar} 29.12 "Hg; T_{Bar} 29.0 °C

time start 1:38 end 2:05 $P_{Bar\,corr}$ _____ "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.780	.83	95	1496	No Load			0	0
	f										
2	s		1.780	.83	95	1122	3.5			24.71	2.90
	f										
3	s		1.780	.83	97	918	4.4			31.07	2.98
	f										
4	s		1.780	.83	97	720	5.4			38.13	2.87
	f										
5	s		1.780	.83	97	626	6.3			44.50	2.92
	f										
6	s		1.780	.83	98	520	6.5			45.90	2.50
	f										
7	s		1.780	.83	98	422	8.5			60.02	2.65
	f										
8	s		1.780	.83	98	322	8.3			56.60	1.91
	f										
9	s		1.780	.83	98	220	9.3			65.66	1.51
	f										
10	s		1.780	.83	100	124	10.2			72.02	0.93
	f										
11	s		1.780	.83	100	75	11.2			79.10	0.62
	f										
12	s		1.780	.83	100	0	9.4			66.37	0
	f										
13	s		1.780	.83	100	1496	No Load				
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

TTU NASA WWT TEST DATA (continued)

Test No. A-12 A
Nom Ind Vel. 5500 fpm
Date 22 June '81

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} 96 °F, P_{Bar} 29.12 "H_2O, T_{Bar} 29.0 °C, Time 2:02

COMMENTS:

TTU-NASA WWT TEST DATA

Test No. K-13

Nom. Wind Vel. 6500 fpm

Date 22 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-12

Test Cond. Same as K-12 (except wind vel.)

Observer(s) _____ T_{room} 86 °F; P_{Bar} 29.12 "Hg; T_{Bar} 29.0 °C

time start 2:40 end 3:05 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		2.554	1.20	98	1838	No Load			0	0
	f										
2	s		2.528	1.20	100	1568	3.2			22.59	3.71
	f										
3	s		2.545	1.20	100	1358	4.6			32.48	4.62
	f										
4	s		2.543	1.20	102	1162	5.9			41.66	5.07
	f										
5	s		2.532	1.20	102	962	7.0			49.43	4.98
	f										
6	s		2.532	1.20	102	868	7.6			53.66	4.87
	f										
7	s		2.532	1.20	102	763	8.3			58.60	4.68
	f										
8	s		2.523	1.20	102	656	9.7			68.50	4.70
	f										
9	s		2.523	1.20	103	561	9.7			68.50	4.02
	f										
10	s		2.523	1.20	103	465	11.5			82.61	4.02
	f										
11	s		2.510	1.20	103	362	11.9			84.02	3.18
	f										
12	s		2.510	1.20	105	262	12.8			90.38	2.48
	f										
13	s		2.510	1.20	105	161	14.3			100.1	1.69
	f										
14	s		2.510	1.20	105	100	15.5			109.4	1.14
	f										
15	*s		2.510	1.20	105	0	9.4			66.37	0
	f										
16	s		2.510	1.20	105	1824	No Load				
	f										
17	s										
	f										

COMMENTS: *It has been noted the stall torque shifts from a higher average to a lower one, e.g. Pt. 15 – 10.4 to 9.4. Is this part of the slippage problem? (over)

TTU NASA WWT TEST DATA (continued)

Test No. _____
Nominal Wind Vel. _____ fpm
Date _____

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V $"H_2O$	Static Press P_S $"H_2O$	Temp T °F	Shaft Speed N RPM	Force (Torque Arm) F gm	Velocity V_W fpm	Velocity V_W m/s	Torque T mN·m	Power P Watts
18	s/f										
19	s/f										
20	s/f										
21	s/f										
22	s/f										
23	s/f										
24	s/f										
25	s/f										
26	s/f										
27	s/f										
28	s/f										
29	s/f										
30	s/f										
31	s/f										
32	s/f										
33	s/f										
34	s/f										

Final Room Data: T_{room} 87 °F, P_{Bar} 29.10 $"H_2O$, T_{Bar} 29.5 °C, Time 3.05

COMMENTS: Why should this stall torque be the same as K-12, when the the overall torque of K-13 is greater than K-12

TTU-NASA WWT TEST DATA

Test No. K-14
Nom. Wind Vel. 5500 fpm
Date 23 June '91

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine performance with selected ports blocked

Test Cond. Front Port open - wheel and wings blocked

Observer(s) M. A. Cook T_{room} 82 °F; P_{Bar} 29.28 "Hg; T_{Bar} 27.5 °C

time start 9:05 end 9:24 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) oz/in	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
1	s		1.802	.82	87	962	No Load			0	0
	f										
2	s		1.802	.82	87	528	3.7			26.12	1.44
	f										
3	s		1.802	.82	87	425	4.2			29.65	1.32
	f										
4	s		1.802	.82	89	329	4.7			33.18	1.14
	f										
5	s		1.802	.82	89	223	5.8			40.95	0.95
	f										
6	s		1.802	.82	89	128	6.2			43.78	0.58
	f										
7	s		1.862	.82	89	81	6.7			47.31	0.40
	f										
8	s		1.862	.82	90	0	4.1			28.95	0
	f										
9	s		1.862	.82	90	964	No Load				
	f										
10	s										
	f										
11	s										
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Test No. K-14 pg.

Nom Wind Vel. 5500 fpm

Date 23 June '81

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Force (Torque) Arm) F gm	Velocity V_w fpm	Velocity V_w m/s	Torque T mN·m	Power P Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
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28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 82 °F, P_{Bar} 29.28 "H_2O, T_{Bar} 27.5 °C, Time 9:24

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-15
Nom. Wind Vel. 6.566
Date 23 June '81

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-14

Test Cond. Same as K-14 (except wind vel.)

Observer(s) M. A. Cowell T_{room} 82 °F; P_{Bar} 29.69 "Hg; T_{Bar} 27.5 °C
time start 9:50 end 9:51 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.587	1.16	92	1184	No Load			0	0
	f										
2	s		2.587	1.18	92	816	3.4			24.00	2.05
	f										
3	s		2.567	1.18	92	718	4.5			31.80	2.39
	f										
4	s		2.567	1.18	95	617	5.4			38.13	2.46
	f										
5	s		2.567	1.18	95	515	5.6			39.54	2.13
	f										
6	s		2.567	1.18	95	417	7.3			51.54	2.25
	f										
7	s		2.567	1.18	95	312	8.0			56.49	1.84
	f										
8	s		2.567	1.18	97	214	8.3			58.60	1.31
	f										
9	s		2.567	1.18	97	114	9.7			68.49	0.82
	f										
10	s		2.567	1.18	97	85	9.1			64.25	0.57
	f										
11	s		2.567	1.18	97	0	8.7			61.43	0
	f										
12	s		2.545 ?	1.18	100	1190	No Load				
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Test No. A-1.5 pg

Nom. C .d Vel. 6.5cc fpm

TTU NASA WT TEST DATA (continued)

Date 23 June '81

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V $"H_2O$	Static Press P_S $"H_2O$	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s						/				
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 83 °F, P_{Bar} 29.20 "Hg, T_{Bar} 27.5 °C, Time 9:51

COMMENTS: _____

Test No. K-12
Nom. Wind Vel. 5500
Date 23 June '81

TTU-NASA WWT TEST DATA

Performance Test of Model K-3 WWT, Config. _____

Test Objective Determine Performance with Selected Ports blocked

Test Cond. Front Port and Wings Open — Wheel blocked

Observer(s) M. A. Cook T_{room} 84 °F; P_{Bar} 29.30 "Hg; T_{Bar} 28.0 °C

time start 10:40 end 11:05 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.	s/f	Time	WIND TUNNEL DATA: Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.816	.84	92	1822	No Load			0	0
	f										
2	s		1.813	.84	92	1615	3.4			24.00	4.06
	f										
3	s		1.813	.84	93	1417	5.9			41.65	6.18
	f										
4	s		1.813	.84	93	1217	8.2			57.90	7.38
	f										
5	s		1.813	.84	96	1017	10.8			76.26	7.73
	f										
6	s		1.786	.84	96	819	13.1			92.50	7.93
	f										
7	s		1.806	.84	96	716	13.6			96.02	7.20
	f										
8	s		1.806	.84	98	614	14.0			98.85	6.35
	f										
9	s		1.806	.84	98	514	15.2			107.3	5.77
	f										
10	s		1.796	.84	98	417	14.4			101.7	4.44
	f										
11	s		1.796	.84	100	316	15.7			110.9	3.66
	f										
12	s		1.796	.84	100	216	16.6			117.2	2.65
	f										
13	s		1.796	.84	100	114	17.2			121.4	1.45
	f										
14	s		1.796	.84	100	0	11.5			81.2	0
	f										
15	s		1.796	.84	101	1820	No Load				
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: _____

Nom. WT Vel. 5500 fpm

TTU NASA WWT TEST DATA (continued)

Date 23 Jan 91

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85 °F, P_{Bar} 29.3 "Hg, T_{Bar} 29.0 °C, Time 11:09

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-17
Nom. Wind Vel. 6500
Date 23 June '71

Performance Test of Model K-3 WWT, Config. _____

Test Objective Same as K-16

Test Cond. Same as K-16 (except wind vel.)

Observer(s) M. A. Cairel T_{room} 95 °F; P_{Bar} 29.30 "Hg; T_{Bar} 28.0 °C
time start 11:40 end 12:13 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) In-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.552	1.20	92	2183	No Load			0	6
	f										
2	s		2.548	1.20	97	2020	3.2			22.59	4.78
	f										
3	s		2.548	1.20	97	1818	6.6			46.60	8.87
	f										
4	s		2.514	1.20	100	1620	9.3			65.66	11.14
	f										
5	s		2.523	1.20	100	1419	11.5			81.20	12.06
	f										
6	s		2.523	1.18	102	1222	14.3			100.8	12.90
	f										
7	s		2.523	1.18	102	1019	16.9			119.3	12.73
	f										
8	s		2.523	1.18	102	922	18.5			130.6	12.61
	f										
9	s		2.523	1.18	105	820	19.5			137.7	11.82
	f										
10	s		2.523	1.18	105	722	19.3			136.3	10.30
	f										
11	s		2.523	1.18	105	621	20.3			143.3	9.32
	f										
12	s		2.523	1.18	105	515	20.6			145.5	7.84
	f										
13	s		2.518	1.18	105	416	22.0			155.3	6.76
	f										
14	s		2.519	1.18	107	315	22.4			158.2	5.22
	f										
15	s		2.519	1.18	107	216	22.7			160.3	3.62
	f										
16	s		2.519	1.18	107	186	22.9			161.7	3.15
	f										
17	s		2.519	1.18	107	0	12.2			86.1	0
	f										

COMMENTS: over for No Load

Nom. V, Vel. 6500 fpm

Date 23 Nov 87

TTU NASA WVT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s		2.519	1.18	107	2176	No load				
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
	f										
24	s										
	f										
25	s										
	f										
26	s										
	f										
27	s										
	f										
28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85.5 °F, P_{Bar} ~~29.90~~ 29.28 "Hg, T_{Bar} 29.5 °C, Time 12:13

COMMENTS:

TTU-NASA WWT TEST DATA

Test No. K-18
Nom. Wind Vel. 5500
Date 23 June '71

Performance Test of Model K-3 WWT, Config. _____
Test Objective Determine Performance with selected ports blocked
Test Cond. Front Port Blocked — Wings and Wheel open
Observer(s) M. A. Cordill T_{room} 85 °F; P_{Bar} 29.27 "Hg; T_{Bar} 28.5 °C
time start 1:35 end 2:08 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.	s/f	Time	WIND TUNNEL DATA: Vel Press P_v "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		1.741	.87	93	2082	No Load			0	0
	f										
2	s		1.791	.87	93	1889	3.5			24.71	4.89
	f										
3	s		~~1.784~~ 1.787	.87	93	1685	6.1			43.07	7.60
	f										
4	s		1.787	.87	96	1482	8.1			57.20	8.87
	f										
5	s		1.787	.87	96	1285	10.3			72.73	9.78
	f										
6	s		1.787	.87	96	1091	12.4			87.55	10.00
	f										
7	s		1.787	.87	96	997	13.5			95.32	4.95
	f										
8	s		1.787	.87	98	890	14.9			105.2	9.90
	f										
9	s		1.761	.85	98	782	16.5			116.5	9.54
	f										
10	s		1.761	.85	98	664	17.3			122.1	8.74
	f										
11	s		1.761	.85	98	584	17.7			125.0	7.64
	f										
12	s		1.761	.85	100	483	17.2			121.4	6.14
	f										
13	s		1.761	.85	100	383	16.5			116.5	4.67
	f										
14	s		1.761	.85	100	284	18.2			128.5	3.82
	f										
15	s		1.761	.85	100	188	19.0			134.1	2.64
	f										
16	s		1.761	.85	102	0	10.6			74.8	0
	f										
17	s		1.761	.85	102	2078	No Load				
	f										

COMMENTS: _____

Nom. WC 3 Vel. 5500 fpm

Date 23 June '87

TTU NASA WWT TEST DATA (continued)

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_S "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_W fpm	Velocity V_W m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
18	s										
	f										
19	s										
	f										
20	s										
	f										
21	s										
	f										
22	s										
	f										
23	s										
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27	s										
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28	s										
	f										
29	s										
	f										
30	s										
	f										
31	s										
	f										
32	s										
	f										
33	s										
	f										
34	s										
	f										

Final Room Data: T_{room} 85.5 °F, P_{Bar} 29.27 "Hg, T_{Bar} 28.5 °C, Time 2108

COMMENTS: _____

TTU-NASA WWT TEST DATA

Test No. K-19
Nom. Wind Vel. 65-00
Date 24 June '81

Performance Test of Model ____ WWT, Config. ____

Test Objective Same as K-18

Test Cond. Same as K-18 (except wind vel.)

Observer(s) W. A. Cabral T_{room} 83 °F; P_{Bar} 29.32 "Hg; T_{Bar} 28.0 °C

time start 8:55 end 9:15 $P_{Bar_{corr}}$ 0 "Hg

Data Pt. No.		Time	WIND TUNNEL DATA Vel Press P_V "H_2O	Static Press P_s "H_2O	Temp T °F	Shaft Speed N RPM	Torque (Torque-meter) in-oz	Velocity V_w fpm	Velocity V_w m/s	Torque T (Calc.) mN·m	Power P (Calc.) Watts
1	s		2.594	1.25	85	2475	No Load			0	0
	f										
2	s		2.594	1.25	87	2307	3.3			23.30	5.63
	f										
3	s		2.594	1.25	87	2102	6.5			45.90	10.10
	f										
4	s		2.586	1.25	89	1902	9.2			64.96	12.94
	f										
5	s		2.586	1.25	92	1705	11.8			83.32	14.87
	f										
6	s		2.577	1.25	92	1505	15.1			106.6	16.80
	f										
7	s		2.577	1.25	92	1300	17.6			124.3	16.92
	f										
8	s		2.563	1.25	95	1112	19.9			140.5	16.36
	f										
9	s		2.552	1.25	95	909	23.3			164.5	15.65
	f										
10	s		2.552	1.25	95	703	25.2			177.9	13.09
	f										
11	s		2.552	1.25	97	567	25.0			176.5	11.03
	f										
12	s										
	f										
13	s										
	f										
14	s										
	f										
15	s										
	f										
16	s										
	f										
17	s										
	f										

COMMENTS: Slippage at shaft outside tunnel

Final: P_B = 29.32 T_B = 28.0°C Time 9:15

APPENDIX B
CALCULATIONS

1. Wind Velocity - from wind tunnel measurements

$$V_w = \frac{2 P_v}{\rho_w}$$

P_v, velocity pressure in psf units

$P_v = P_v'(\text{"}H_2O)\ 5.2 \frac{psf}{\text{"}H_2O}$

P_s = static pressure

$$P_w = \frac{P}{RT}_{Tunnel} = \frac{P_{Bar}(\text{"Hg})70.75 + P_s(\text{"}H_2O)5.2 \frac{Psf}{\text{"}H_2O}}{53.35\ T_w(°F) + 460}$$

T_w = wind tunnel temperature in °F

R = specific gas constant = 53.35 $\frac{ft\ lbf}{lbm\ °R}$ for air

$$V_w = \left\langle \frac{2(5.2)P_v'\ (T_w + 460)\ g_c}{1.326\ P_{Bar} + 0.0975\ P_s} \right\rangle^{1/2} \frac{ft}{sec}$$

2. Blade Velocity - of WWT rotor

$$V_B = V_{Blade\ Tip} = \omega R = 2\pi \left\langle \frac{N(rpm)}{60} \right\rangle R(ft)$$

3. Wind Power - in wind tunnel

$$P_w = \rho_w A_c V_w \left(\frac{V_w^2}{2}\right)$$

ρ_w = density = $\frac{P}{RT}$ as above

A_c = wind collector area in ft^2

V_w = wind velocity in ft/sec

$P_w = 0.042\ \rho A_c V^3$ watts

4. Shaft Power - measured by torque transducer

$P_{sh} = cTN =$

T = measured torque in milli-Newton meters (mNm)

N = measured shaft speed in Rev/min

C = conversion factor

$P_{sh} = 0.1047T\left(\frac{N}{1000}\right)$ watts

5. Power Coefficient

$$C_p = \frac{P_{sh}}{P_w} = \frac{0.1047T\left\langle \frac{N}{1000} \right\rangle}{0.042\rho A_c V^3}$$ dimensionless

6. Speed Ratio

$$\frac{V_{Rotor}}{V_w} = \frac{V_B}{V_w} = \frac{\frac{2\pi \frac{N}{60}}{10.4P_v'(T_w + 460)g_c}}{1.326P_{Bar} + 0.0975P_s}$$ dimensionless